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# Reconnaissance Study of Leachate Quality from Raw Mined Oil Shale - Laboratory Columns

Colorado State Univ.
Fort Collins

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In one set of tests, the initial saturated leaching was followed by a second saturated leaching after a period of drainage and aeration. The tests on the soils and previously exposed shales were conducted to provide a basis for comparison of the results from the raw mined shales. The results indicate that leachates from mined shales will contain dissolved solids at levels substantially greater than the background levels as indicated by the soils and previously exposed shales. This study indicates that the trace elements Al, B, F, Zn, Pb and possibly Mo occur in the leachates from some of the mined shales in quantities significantly greater than in the leachates from the background materials. All other trace elements considered in this study were present in the effluents from the mined shales in about the same concentration as observed in the leachates from the soils and previously exposed shales.

Although the maximum observed concentrations of Cr, F, Fe, Hg, Mn, $NO_3$, Pb, $SO_4$, TDS, and Zn were found to exceed the respective drinking water criteria, in no case did the concentration of measured constitutents exceed the standard by 100 fold.

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# RECONNAISSANCE STUDY OF LEACHATE QUALITY FROM RAW MINED OIL SHALE - LABORATORY COLUMNS

by
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## FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollutional control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL - Ci) assists in developing and demonstrating new and improved methodologies that will meet these meeds both efficiently and economically.

This report presents the results of the chemical characterization of leachates generated from laboratory columns of several unretorted mined oil shales, unmined shales, and soils. The findings are indicators of the levels of common and trace species that can be expected to occur in field generated leachates. For further information contact the Energy Pollution Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

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## ABSTRACT

Columns of mined raw oil shale, soils, and previously exposed oil shales were leached with de-ionized water in the laboratory as a means of characterizing the quality of leachates that will be generated from surface storage of mined shale. Leaching was conducted under saturated conditions and unsaturated conditions. In one set of tests, the initial saturated leaching was followed by a second saturated leaching after a period of drainage and aeration. The tests on the soils and previously exposed shales were conducted to provide a basis for comparison of the results from the raw mined shales. The results indicate that leachates from mined shales will contain dissolved solids at levels substantially greater than the background levels as indicated by the soils and previously exposed shales. This study indicates that the trace elements Al, B, F, Zn, Pb and possibly Mo occur in the leachates from some of the mined shales in quantities significantly greater than in the leachates from the background materials. All other trace elements considered in this study were present in the effluents from the mined shales in about the same concentration as observed in the leachates from the soils and previously exposed shales.

Although the maximum observed concentrations of Cr, F, Fe, Hg, Mn, $NO_3$, Pb, $SO_4$, TDS, and Zn were found to exceed the respective drinking water criteria, in no case did the concentration of measured constituents exceed the standard by 100 fold.

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# SECTION 1

## INTRODUCTION

The modified in-situ method of oil shale retorting and the various surface methods require that quantities of raw (unretorted) shale be mined from shafts and drifts that provide access to the retorts. Raw shale is also mined to provide a void space into which the shale in the retort expands upon rubblization by blasting. The mined shale will be stored on the ground surface for a period of at least a few years and possibly even permanently. The placement of the unretorted shale on the surface places it in an environment with which it is no longer in geochemical equilibrium, and the precipitation on the pile creates the potential for the release of a variety of chemicals into percolating waters at elevated levels relative to the base line conditions.

There is no single generally accepted method by which the effect of solid waste upon the chemistry of percolating waters can be assessed. Most of the comparative studies of leaching methods have been oriented toward landfill problems (Löwenbach, 1978; Ham et al., 1979). It is not practical to simulate in the laboratory the wet and dry cycles, the freeze and thaw sequences, the microbial activity, the aerobic and anaerobic conditions, temperature fluctuations, and variable residence times that will be experienced in the field.

Futhermore, the chemical and physical properties of raw mined shale cannot be expected to be uniform. This natural heterogeneity imposes an additional constraint on the extrapolation and generalizations of laboratory results.

This report contains the results of a laboratory based reconnaissance study of potential water quality problems associated with leachate from surface storage of raw shale. In view of the fact that laboratory tests are not capable of simulating field conditions, the results of this study must be viewed only as a general indicator of the water quality that can be expected in leachates from raw shale. A major purpose of the study was to investigate whether or not more realistic and comprehensive field tests are warranted.

Eight different materials were subjected to leaching. Four of the materials were raw mined shales obtained at different locations in the Colorado oil shale region. The other four materials were samples of shales and soils that had been exposed to natural leaching processes. The four previously exposed materials provide a background or baseline that assisted in

placing the results for the mined shales in an appropriate perspective. No attempt was made to establish statistical distributions of the concentrations of the various chemical constituents. Because the laboratory conditions do not adequately simulate those in the field, rigorous establishment of the ranges of variation for various confidence intervals was not warranted.

Leaching was conducted by passing de-ionized water through columns of each material. Both saturated and unsaturated tests were conducted. Samples of the effluents were collected and subjected to chemical analyses. The electrical conductivity of the effluent from the columns was measured at small time intervals by means of a flow-through probe and a data logger. Grain size analyses were made for each material. The results of these experiments are summarized in the body of the report. All of the data generated from the chemical analyses are contained in the appendices. Graphical representations of the grain-size distributions are also included in the appendices.

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# SECTION 2

# CONCLUSIONS

Raw mined shales of the type tested in this study can be expected to result in leachate containing dissolved solids at elevated concentrations relative to the background. The major contributors to the dissolved solids content are calcium, magnesium, sodium, bicarbonate, chloride and sulfate. Using the electrical conductivity (EC) as an indicator of the dissolved solids concentration, it was found that the dependence of the EC on the throughput volume could be satisfactorily described by

$$EC = EC_m \left( \frac{PV}{PV_m} \right)^{-\alpha}, \quad PV \geq PV_m$$

where PV is the effluent volume expressed in pore volumes, $EC_m$ is the maximum EC observed and $PV_m$ is the corresponding effluent volume. The exponent $\alpha$ is an indicator of the leachability; large $\alpha$ representing a more rapid decline in EC than for small $\alpha$, other factors being equal. This equation does not hold at large PV where the EC is approaching a stable value.

The leaching index $\alpha$ for the mined shales ranged between 0.4 and 1.1. The USBM, Colony, and C-a composite materials exhibited remarkably similar values of $\alpha$ that ranged between 0.8 and 1.1. The C-a, R-5/Mahogany material had a leaching index of 0.4-0.5. For the materials tested, the leaching index did not depend upon whether the test was conducted under saturated or unsaturated conditions. Futhermore, nearly identical values of $\alpha$ were obtained for the mined shales on a second leaching cycle following a period of drainage and aeration.

In contrast to the mined shales, the values of $\alpha$ obtained for the soils and previously exposed shales on the second leaching cycle were markedly reduced from the values obtained on the first cycle. It is likely that the readily leachable precipitates in the previously exposed materials are largely deposits on the surface of the grains left by evaporating waters. Once the deposits were leached away in the first cycle, they could not be readily replaced because leaching by precipitation over many decades has removed the source. In the case of the mined shales, diffusion of dissolved solids and capillary flow from the interior to particle surfaces during the drainage/aeration period is proposed as the cause of the observed recovery.

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The concentrations of Al, B, F and Zn were found to be significantly greater in the leachates from some of the mined shales than in the corresponding samples from the previously exposed materials. The levels of all other trace elements produced by the mined shales were comparable to those observed from the soils and previously exposed shales. Elevated concentrations of Al, B, F and Zn were measured in leachates from the USBM raw shale. The largest values of Al concentration were produced from the unsaturated leaching tests and the second cycle of saturated leaching. No consistent relation between Al concentration and the volume of effluent was found.

The largest concentrations of B were also found in the leachates from the USBM shale columns. A trend toward decreasing concentration of B with increasing leachate volume was observed for all of the mined shales. Concentrations of B did not increase significantly during the period of drainage/aeration.

Fluorine concentrations in the leachates from the mined shales was generally greater than from the previous exposed materials. Concentrations of F decreased rapidly with the first pore volume of effluent from the USBM and C-a R-5/Mahogany mined shales and then approximately stabilized. A similiar leaching effect for the soils was observed, but the concentration of F in leachate from the other materials did not decline significantly. After the concentration was approximately stable, the range of F concentrations for the mined shales was 1-25 mg/l. Only the USBM shale yielded F concentrations consistently greater than 10 mg/l.

The concentration of Zn in the effluent from the USBM shale was consistently greater than for any of the other materials tested. The other mined shales yielded Zn concentrations comparable to those obtained in the background materials.

From comparisons of the maximum observed concentrations of various parameters with drinking water criteria, it is concluded that even the worst leachate from the columns does not exceed 100 times drinking water standards for measured parameters. The maximum concentrations of Cr, F, Fe, Hg, Mn, $NO_3$, Pb, $SO_4$, TDS, and Zn were found to exceed drinking water criteria, however. After leaching, the minimum concentrations generally fell well below the standards with the exception of F.

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# SECTION 3

## RECOMMENDATIONS

It is recommended that the chemical constituents of the leachates generated under field conditions be determined. The present study indicates that particular emphasis should be placed upon the total dissolved solids and the trace elements Al, B, F and Zn, although only B and F were found at significantly elevated levels in all of the mined shales tested. There was some indication that Mo concentrations in leachates from the C-a R-5/Mahogany mined shale are significantly above background values. It is recommended that this element be given additional study. It is recommended that the sulfur chemistry be given additional attention. There is a need to determine the levels of sulfur species other than sulfate in the leachates.

At the present time, little is known about the geochemical and biological processes that result in the release of these trace elements to the percolating waters. An understanding of these processes would assist in projecting long term consequences and might suggest methods or practices that would minimize the degradation of the quality of waters contacting the materials.

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# SECTION 4

## MATERIALS AND METHODS

A variety of samples of raw shale and soils was obtained from the Piceance Basin of Colorado for use in this study. The purpose of extending the study to selected soil samples was to provide a background and perspective from which the results on the raw shale can be viewed. A total of eight different materials were tested; four raw shales, two soils, one sample of naturally leached outcropping shale, and one sample of naturally retorted shale from a surface fire of unknown age.

### DESIGNATION AND SOURCE OF SAMPLES

Two samples of raw shale were obtained from federal lease tract C-a with the cooperation of Rio Blanco Oil Shale Company. One of these is a sample of mixed ore from the R-5 and Mahogany zones and is designated C-a R-5/Mahogany in the remainder of this report. The second sample from this site is designated C-a composite and represents a sample of the trimmings from the service shaft.

A sample of unretorted shale from the Mahogany zone was obtained with the cooperation of Colony Development Operation from the mine on Parachute Creek. This sample was extracted from a stock pile of minus 1/2 inch material that was mined approximately 6 years ago. The sample was collected from well beneath the surface of the pile but has, undoubtedly, been subjected to some weathering and leaching prior to testing. This sample is called Colony raw shale throughout the report.

The fourth raw shale sample was obtained from the United States Bureau of Mines site in Horse Draw. This material is from a drift at 4208 MSL elevation in the saline zone and had been stockpiled outside for approximately 6 weeks.

Soil samples were collected from two locations. The sample designated Colony soil was obtained in the vicinity of the crusher and stockpile at the Colony site on Parachute Creek and was scraped directly from the surface. The second sample was obtained from the B-horizon exposed in a small cut in Cottonwood Gulch on the C-b federal lease tract. These samples are designated Colony soil and C-b soil, respectively.

The other two materials tested are designated Colony naturally leached and Union naturally retorted. The first is talus slope material collected near the mine on Parachute Creek. This material has been exposed to

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weathering and leaching and is presumed to be in approximate equilibrium with the surface environment. The material designated as Union naturally retorted shale is shale that has burned under natural conditions and was obtained near the portal of Union's mine on Parachute Creek. The age of the burn is unknown but probably occurred many decades ago.

## PARTICLE SIZE ANALYSIS

Quantities of each material sufficient to fill the leaching columns were separated from the samples collected. These quantities were quartered and samples were taken for particle size analysis. These samples were prepared for analysis in accordance with the standard method for "Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants" (ASTM D421-58). The distribution of particle sizes was determined in accordance with the standard method for "Particle-Size Analysis of Soils" (ASTM D422-63).

## LEACHING METHODS

Columns constructed of PVC pipe, 15 cm in diameter, were used to contain the materials during leaching. The columns were capped on the lower end and an outlet was provided as shown in Figure 1. The effluent was forced to pass through an electrical conductivity probe that was connected to an automatic data logger. Below the sample, a layer of glass beads and silica sand was placed to prevent the movement of fines into the outflow. The length of the sample was 107 cm.

Two sets of experiments were performed. In one set, the flow through the columns was controlled so that the sample remained saturated. In the second set, the flow was controlled so that the major portion of the column was unsaturated. The inflow to the columns in the saturated flow experiments was controlled by means of a Mariotte siphon placed on a platform whose position could be adjusted to any desired elevation. A small depth of ponded water was maintained on the surface of the sample at all times during the experiments with saturated flow. The elevation of the outflow tube was adjusted to maintain the desired flow rate.

The inflow to the unsaturated column experiments was provided by means of positive displacement, constant rate pumps. In these runs, the elevation of the outflow tube was maintained near the level of the bottom of the sample, and inflow was provided at a rate per unit area less than the value of saturated hydraulic conductivity. This procedure insured that the pressure of the water in the column was less than atmospheric everywhere except in the immediate vicinity of the bottom of the column. The degree of aeration in the upper portion of the column was not quantified.

With the exception of the soils, the saturated hydraulic conductivities of the materials were rather large. Therefore, during the saturated runs, the differences in elevation between the water surface in the columns and the outflow had to be maintained at a small value to insure reasonable residence times in the columns. Small changes in the difference in head were

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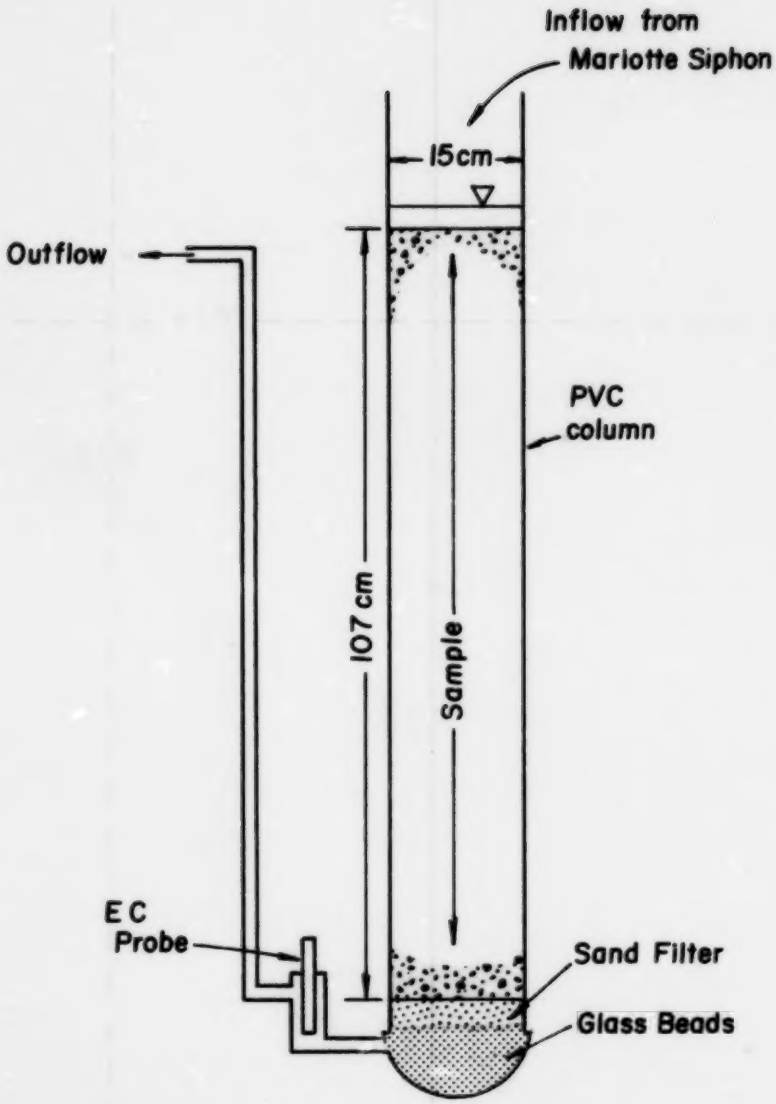


Figure 1. Schematic diagram of leaching apparatus.

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thus large relative to the total difference and this caused the inflow rate to be somewhat variable.

The inflow rate per unit area during the unsaturated runs was maintained below the value of saturated hydraulic conductivity. The fact that the hydraulic conductivity was large made it possible to maintain unsaturated conditions with inflow rates that were substantially greater than those used in the saturated runs. Therefore, the residence times for the unsaturated columns were actually less than for the saturated columns. Quantitative residence times for the unsaturated columns could not be calculated because the water content (degree of saturation) was not known. However, the residence times in the unsaturated columns is less than the column length divided by the inflow rate per unit area.

Effluent was collected from the columns continuously and the cumulative volume was measured. The electrical conductivity of the effluent was recorded automatically every two hours. At least daily, the effluent was sampled and the pH and EC measured. Samples of the effluent were collected periodically and subjected to a chemical analysis described subsequently. Influent in all experiments was deionized water.

## METHODS OF CHEMICAL ANALYSIS

Chemical analyses were performed at the analytical laboratory in the Chemistry Department at Colorado State University under the direction of Dr. Rodney Skogerboe. Table 1 summarizes the methods utilized. The degree of accuracy decreases from those listed in Table 1 when the concentration approaches the determination level.

## LEACHING EXPERIMENTS CONDUCTED

All of the materials described previously were subjected to saturated leaching testing and most were also subjected to unsaturated leaching. In addition, several of the materials were allowed to gravity drain and stand in an aerated condition for several weeks and were then subjected to saturated leaching a second time. Funds available for chemical analysis did not permit a complete chemical analysis in all cases. Table 2 contains a summary of the tests conducted. In those runs for which a chemical analysis is indicated, between one and seven samples were analyzed.

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TABLE 1. SUMMARY OF ANALYTICAL METHODS AND LEVELS OF ACCURACY

| Constituent | Method | Level of Accuracy |
|---|---|---|
| B | Eschelle Multi-element Plasma Spectrometer | ± 20% |
| Cd | " | " |
| Be | " | " |
| Mg | " | " |
| Si | " | " |
| Mo | " | " |
| Mn | " | " |
| Ni | " | " |
| Na | " | " |
| Cu | " | " |
| Al | " | " |
| Ca | " | " |
| Ba | " | " |
| K | " | " |
| Cr | " | " |
| Sr | " | " |
| Pb | " | " |
| Sn | Eschelle Single-element Plasma Spectrometer | " |
| F | Dionex Ion Chromatograph | ± 10% |
| Cl | " | " |
| $NO_3$ | " | " |
| $SO_4$ | " | " |
| As | Atomic Absorption-Hydride Gen. | " |
| Se | " | " |
| Hg | Atomic Absorption-Cold Vapor | " |
| Fe | Atomic Absorption-Flame | " |
| Li | " | " |
| Zn | " | " |
| $HCO_3$ | Calculated | " |
| $CO_3$ | " | " |

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TABLE 2. SUMMARY OF THE TESTS CONDUCTED

| MATERIAL | SATURATED | | | | UNSATURATED | |
|---|---|---|---|---|---|---|
| | Initial | | After Aeration | | | |
| | # of Runs | # w/Chem Anal | # of Runs | # w/Chem Anal | # of Runs | # w/Chem Anal |
| USBM Raw Shale | 2 | 2 | 2 | 1 | 1 | 1 |
| Colony Raw Shale | 2 | 2 | 2 | 1 | 1 | 0 |
| C-a R-5 Mahogany | 2 | 1 | 2 | 0 | 1 | 1 |
| C-a Composite | 2 | 1 | 2 | 0 | 1 | 1 |
| Colony Naturally Leached | 1 | 1 | 1 | 1 | 1 | 0 |
| Union Naturally Retorted | 1 | 1 | 1 | 0 | 1 | 1 |
| Colony Soil | 1 | 1 | 1 | 1 | 0 | 0 |
| C-b Soil | 1 | 1 | 0 | 0 | 0 | 0 |
| | 12 | 10 | 11 | 4 | 6 | 4 |

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# SECTION 5

## RESULTS

The leaching characteristics of the materials studied are presented in this section. The results are divided into three categories; the first being a summary overview of the range of concentrations observed in leachates. The observations relative to the leaching of the common elements that make up the majority of the dissolved solids are presented, and finally the results obtained for selected trace elements are summarized. The chemical analyses for each individual sample of leachate are tabulated in the appendices.

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### RANGE OF CONCENTRATIONS OBSERVED

Raw shale disposed above ground in the field will be subjected to a variety of weathering processes that probably cannot be adequately simulated in the laboratory. There will be wet and dry cycles, freeze and thaw, microbial activity, periods in which percolation from precipitation is rapid and others in which the contact time will be great. Superimposed upon this variability will be the inherent spatial heterogeneity of the geochemical properties of the materials placed in the embankment. The concentrations of various chemical species in leachates is expected to be highly variable. The results contained in this subsection should be viewed as indicators of the possible range of concentrations that can be anticipated in field disposal.

The range of concentration variation observed in leachates from each material are presented in Table 3. The values in this table were obtained by searching all data for the maximum and minimum values without regard to the cumulative volume of throughput, whether the material was saturated or unsaturated, or the residence time. Thus, this table represents an overview of the magnitudes observed for each species. In most cases the maximum values were obtained early in the leaching process and the minimum values were obtained after several pore volumes of throughput.

As an aid to assessing the significance of the concentrations of several parameters, drinking water criteria are also listed in Table 3. The maximum concentrations of Cr, F, Fe, Hg, Mn, $NO_3$, Pb, $SO_4$, TDS, and Zn exceed their respective recommended maximum drinking water concentrations. The minimum concentrations obtained after substantial leaching are generally well below the drinking water criteria. Fluoride is a major exception to this statement. The ratios of the maximum observed concentration to the respective drinking water standard were calculated. In no case did the ratio

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TABLE 3 - SUMMARY OF THE RANGE OF OBSERVED CONCENTRATIONS

| Parameter | Units | USBM Raw Shale | Colony Raw Shale | C-a R-5/Mahog. Shale | C-a Composite | Colony Nat. Leached | Union Nat. Retorted | Colony Soil | C-b Soil | Drinking Water Criteria |
|---|---|---|---|---|---|---|---|---|---|---|
| Al | mg/l | 0.34 - 7.54 | <0.05 - 0.75 | 0.3 - 3.53 | <0.05 - 0.69 | <0.05 - 0.17 | <0.05 - 0.1 | <0.05 - 0.37 | <0.05 | ---- |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 0.05 |
| B | " | 0.24 - 43 | <0.025 - 2.75 | <0.025 - 0.59 | <0.025 - 1.97 | 0.12 - 0.365 | 0.165 - 0.39 | 0.47 - 0.76 | 0.65 - 0.985 | ---- |
| Ba | " | 0.061 - 0.17 | 0.07 - 0.48 | 0.068 - 0.27 | 0.027 - 0.22 | 0.088 - 0.495 | 0.028 - 0.35 | 0.12 - 0.57 | 0.038 - 0.240 | 1.0 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | ---- |
| Ca | " | 36 - 750 | 40 - 1550 | 180 - 1510 | 18 - 970 | 25 - 500 | 10 - 49 | 40 - 960 | 6.5 - 330 | ---- |
| Cl | " | <1.0 - 560 | 1.1 - 22 | 1.9 - 300 | 0.3 - 130 | 0.8 - 71 | 1.1 - 15 | 0.1 - 200 | 1.8 - 520 | ---- |
| $CO_3$ | " | 0.1 - 1.1 | 0.03 - 1.6 | <0.1 - 346 | 0.3 - 0.7 | 0.12 - 1.03 | <1.0 - 22 | 0.17 - 2.9 | 1.0 - 8.8 | ---- |
| Cr | " | <0.025 - 0.68 | <0.025 - 0.04 | 0.022 - 0.034 | <0.025 - 0.043 | <0.025 | <0.025 - 0.71 | <0.025 | <0.025 - 0.069 | 0.05 |
| Cu | " | <0.025 - 0.30 | <0.025 - 0.41 | <0.025 - 0.69 | <0.025 - 0.44 | <0.039 - 0.31 | <0.025 - 0.33 | 0.075 - 0.38 | <0.025 - 0.28 | 1.0 |
| EC | µmhos/cm | 280 - 13000 | 240 - 5400 | 1900 - 37000 | 125 - 8200 | 240 - 4200 | 300 - 1300 | 370 - 9000 | 840 - 3000 | ---- |
| F | mg/l | 9.5 - 75 | 4.0 - 7.2 | 0.8 - 65 | <0.5 - 3.0 | 4.0 - 8.7 | 5.4 - 6.6 | 1.2 - 10 | 4.5 - 25 | 1.8 |
| Fe | " | 0.01 - 1.8 | <0.03 - 0.89 | <0.1 | <0.1 | <0.03 - 0.08 | <0.05 | <0.01 - 0.52 | 0.1 - 0.42 | 0.3 |
| $HCO_3$ | " | 83.1 - 321 | 50 - 558 | 3.0 - 403 | 82 - 1026 | 136 - 233 | 168 - 585 | 152 - 480 | 481 - 846 | ---- |
| Hg | " | <0.0001 - 0.0035 | <0.0005 | <0.0001 | <0.0001 | <0.0005 | <0.0001 | <0.0005 | <0.0001 | 0.002 |
| K | " | 1.1 - 22 | 1.7 - 59 | 8.2 - 640 | 0.4 - 34 | 0.83 - 57 | 9.2 - 74 | 25 - 270 | 1.3 - 22 | ---- |
| Li | " | 0.02 - 3.1 | 0.02 - 0.151 | 0.02 - 0.11 | <0.02 - 0.79 | <0.004 - 0.02 | 0.14 - 0.51 | 0.03 - 0.47 | 0.02 - 0.08 | ---- |
| Mg | " | 6.7 - 1050 | 5.5 - 140 | 0.675 - 108 | 4.9 - 820 | 17 - 365 | 30 - 108 | 17 - 1450 | 2.6 - 145 | ---- |
| Mn | " | 0.075 - 3.2 | 0.074 - 2.74 | <0.05 - 0.35 | <0.05 - 0.40 | <0.05 - 0.11 | <0.05 | <0.05 - 0.97 | <0.05 - 0.16 | 0.05 |
| MO | " | 0.09 - 0.87 | 0.09 - 0.65 | 0.10 - 5.18 | 0.10 - 2.2 | 0.075 - 0.74 | 0.065 - 0.45 | <0.05 - 0.84 | <0.05 - 0.43 | ---- |
| Na | " | <25 - 1430 | 5.8 - 145 | 27 - 7710 | 4.3 - 1240 | 14 - 350 | 12 - 75 | 3.8 - 340 | 210 - 2050 | ---- |
| Ni | " | <0.025 - 0.60 | <0.05 - 0.10 | 0.047 - 0.085 | <0.05 - 0.16 | <0.05 - 0.06 | <0.05 | <0.05 - 0.07 | <0.05 - 0.075 | ---- |
| $NO_3$ | " | <1.25 - 40 | 0.9 - 25 | 4 - 172 | <0.5 - 140 | <0.3 - 245 | 0.5 - 8 | <0.2 - 180 | 1.4 - 30 | 10 |
| Pb | " | <0.04 - 1.9 | <0.05 - 0.64 | <0.05 - 0.83 | <0.05 - 0.77 | 0.12 - 0.35 | 0.05 - 0.16 | 0.12 - 0.38 | 0.07 - 0.31 | 0.05 |
| pH | --- | 6.8 - 8.06 | 7.06 - 8.18 | 6.93 - 11.98 | 7.03 - 7.99 | 6.93 - 8.11 | 7.20 - 8.81 | 7.1 - 8.2 | 7.43 - 8.49 | ---- |
| Se | mg/l | < 0.01 | <0.01 | <0.005 | <0.005 | <0.01 | <0.005 | <0.01 | <0.005 | 0.01 |
| Si | " | 1.65 - 9.7 | 2.12 - 10.58 | 1.2 - 23.28 | 5.8 - 19.58 | 6.71 - 14.72 | 8.8 - 19.06 | 8.0 - 16.8 | 11.0 - 20.7 | ---- |
| Sn | " | <0.025 - 1.28 | 0.12 - 0.67 | --- | --- | 0.041 - 0.67 | --- | <0.025 - 1.37 | --- | ---- |
| $SO_4$ | " | 20 - 5700 | 28 - 5150 | 5 - 66.0 | 7.9 - 6100 | 15 - 2650 | 9 - 128 | 60 - 4200 | 23 - 860 | 250 |
| TDS | " | 70 - 13300 | 110 - 7160 | 610 - 30130 | 164 - 9450 | 120 - 4760 | 460 - 1200 | 250 - 7450 | 1050 - 3760 | 500 |
| Zn | " | 0.01 - 6.8 | <0.02 - 0.68 | <0.01 - 0.09 | <0.02 - 1.5 | 0.07 - 0.3 | 0.02 - 0.15 | 0.01 - 0.65 | 0.04 - 0.35 | 5.0 |

exceed 100. The largest ratio was found to be 64 for Mn in effluent from USBM raw shale in saturated run number 2. This comparison indicates that even the worst of the leachates generated from the laboratory columns do not exceed 100 times drinking water standards for the parameters measured.

The four materials on the right side of the table have all been exposed to natural leaching. The quality of leachate from these materials is useful for establishing a perspective in which the leachates from the raw shale can be viewed. The maximum dissolved solids in the effluent from the raw shales are significantly greater than in that from the previously exposed materials. The increased dissolved solids are almost entirely attributable to increases in Ca, Mg, Na, $HCO_3$, Cl and $SO_4$ in some combination. In general, the maximum concentrations of trace elements from the raw shales are low and are not often substantially greater than the values measured for the previously exposed materials. One exception is B, the maximum concentration of which was significantly greater in the raw shale leachate (except for C-a R-5/Mahogany). The minimum values of B from the raw shales are within the observed range for the previously exposed materials, indicating the leachability of this species. Boron, F, and Al concentrations are discussed further in a subsequent section.

Calculation of the quantities of anions and cations for the raw shales showed a substantial deficiency of anions, except for the colony raw shales for which an acceptable balance on every sample was observed. There are at least two possibilities that are presently under investigation. First, there may exist an error in the determination of sulfate. For this reason sulfate concentrations on individual samples have not been reported. It is believed that another probable explanation involves the presence of other sulfur species. For instance, thiosulfate ($S_2O_3^{2-}$) is a common constituent of oil shale process waters and Wong and Mercer (1979) found that this species accounted for 7-20 percent of the chemical oxygen demand. A few spot checks of the COD of the leachates from the raw shale showed values ranging between 1000 and 1500 mg/l. This is suggestive that substantial quantities of thiosulfate may be present. Stuber, et al., (1978) analyzed four process waters from in-situ production operations for various sulfur species. They found the percentages of total sulfur to range from: 3.9 to 30.2 as sulfate, 34.8 to 55.2 as thiosulfate, 1.0 to 26.[illegible] as thiocyanate, and <0.3 to 3.5 as tetrathionate. It is not likely that these percentages can be extrapolated to leachates from raw shale, but the possible presence of such species seems to warrant investigation.

## LEACHING OF COMMON SPECIES

The most convenient indicator of the quantity of the common species Ca, Mg, Na, Cl, $HCO_3$ and $SO_4$ in the leachate is the electrical conductivity (EC) of the solution. A measure of the leachability of these species is the rate at which the EC declines with the volume of throughput. Figure 2 shows such a relationship for the USBM raw shale. The two sets of data in the upper block are those obtained under saturated leaching conditions; the black circles being the initial run and the open circles being the

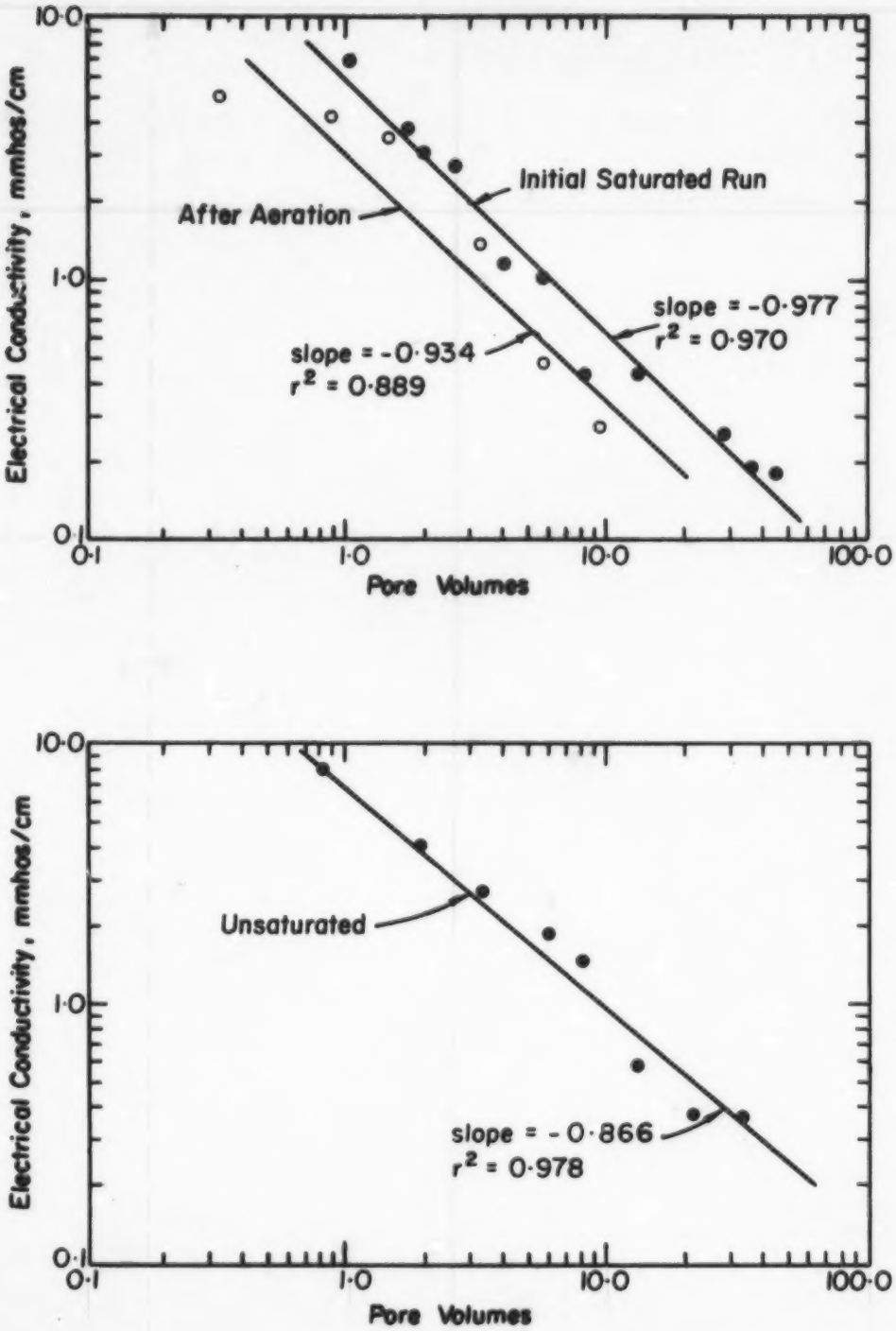



Figure 2. Leaching characteristics of USBM raw shale.

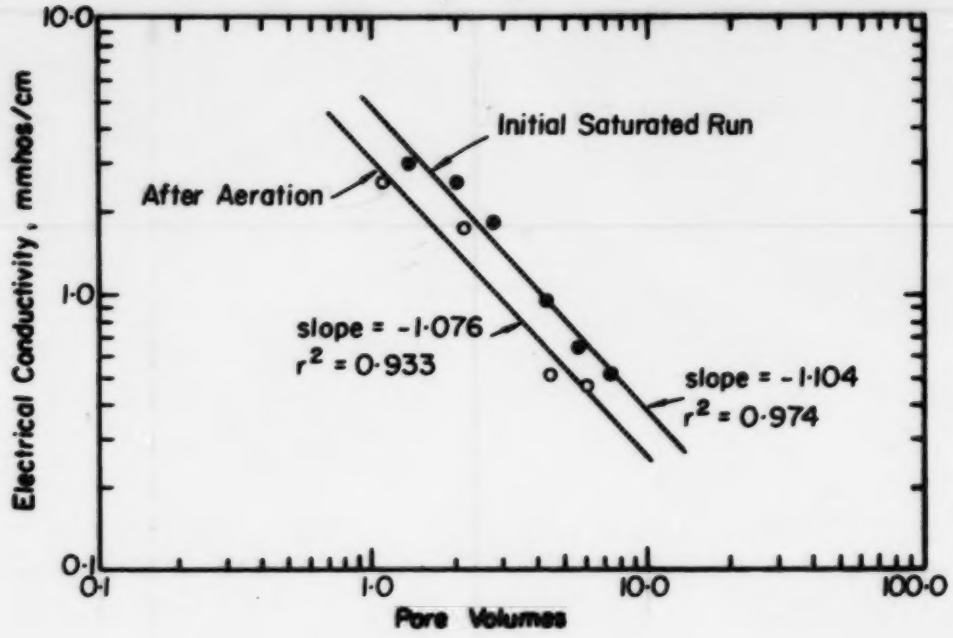
resaturated run. The data in the lower block are those obtained by leaching under partially saturated conditions.

Because the columns were quite permeable and saturated from the top, the residence time of the first few hundred ml of water was much smaller than the mean residence time. This short residence time and probable channeling of flow caused the dissolved solids in the first sample to be less than the maximum. In the preparation of Figure 2 and similar graphs, only values after the maximum were used. This tends to laterally shift the straight line in a rather arbitrary way, but has no affect on the slope of the lines.

The rate of leaching of the common species for the USBM raw shale is practically the same in all three of the experiments. After the initial saturated leaching had been completed, the column was allowed to drain and become aerated for 108 days. Leaching was initiated again and the data indicated by the open circles were obtained. Note that the EC almost completely recovered to its original value and subsequently declined at almost the same rate as in the first run. The mean residence time was 46 hours in these runs. The variation of EC with the volume of throughput during the unsaturated run is, again very similar, even though the residence time during the unsaturated run was less than one-half the residence time for the saturated runs.

Similar results were observed for the other raw shales tested. Figure 3 shows the results for the Colony raw shale. Again the leaching characteristics are practically the same for all three tests. As for the raw shales, the rate of leaching during saturated and unsaturated tests was about the same for the four materials that had been exposed to natural leaching. However, in each of these four cases, the rate of leaching following the drainage/aeration period was markedly less than during the initial run. Examples are shown in Figure 4 and 5 for Colony naturally leached and the Union naturally retorted. Futhermore, the EC did not recover substantially during the aeration period.

In the case of the previously exposed materials, it is believed that the large fraction of the readily leachable materials existed as the result of long term weathering processes and precipitation of dissolved solids caused by the evapotranspiration of soil water. When these materials were leached during the initial run, they were not rapidly replaced. In the raw shales, the percolating waters of the first run removed the readily leachable materials from the surface of the solid particles much as in the case of the previously exposed materials. However, during the aeration period the leachable materials were replenished rapidly to the surfaces, probably by diffusion and capillary flow. The movement of dissolved species to the surfaces of the particles was relatively rapid for the raw shales because no significant leaching on the interior of the particles had occurred and, thus, the concentration gradients were very large. A similar process may still be operative in the other four naturally leached materials, but at a much reduced rate due to the countless number of such cycles experienced previously.



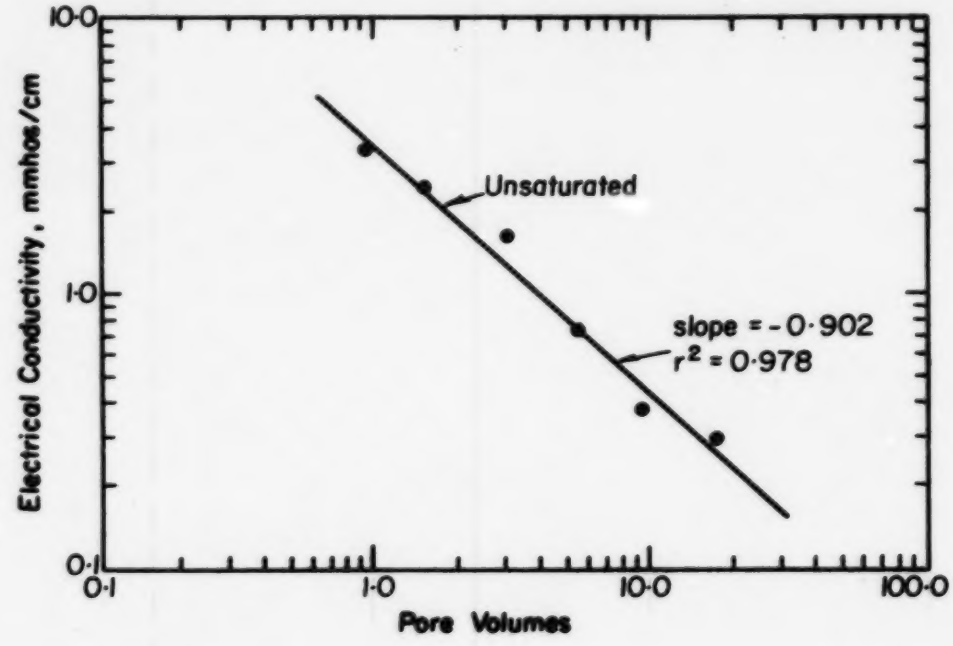




Figure 3. Leaching characteristics of Colony raw shale.

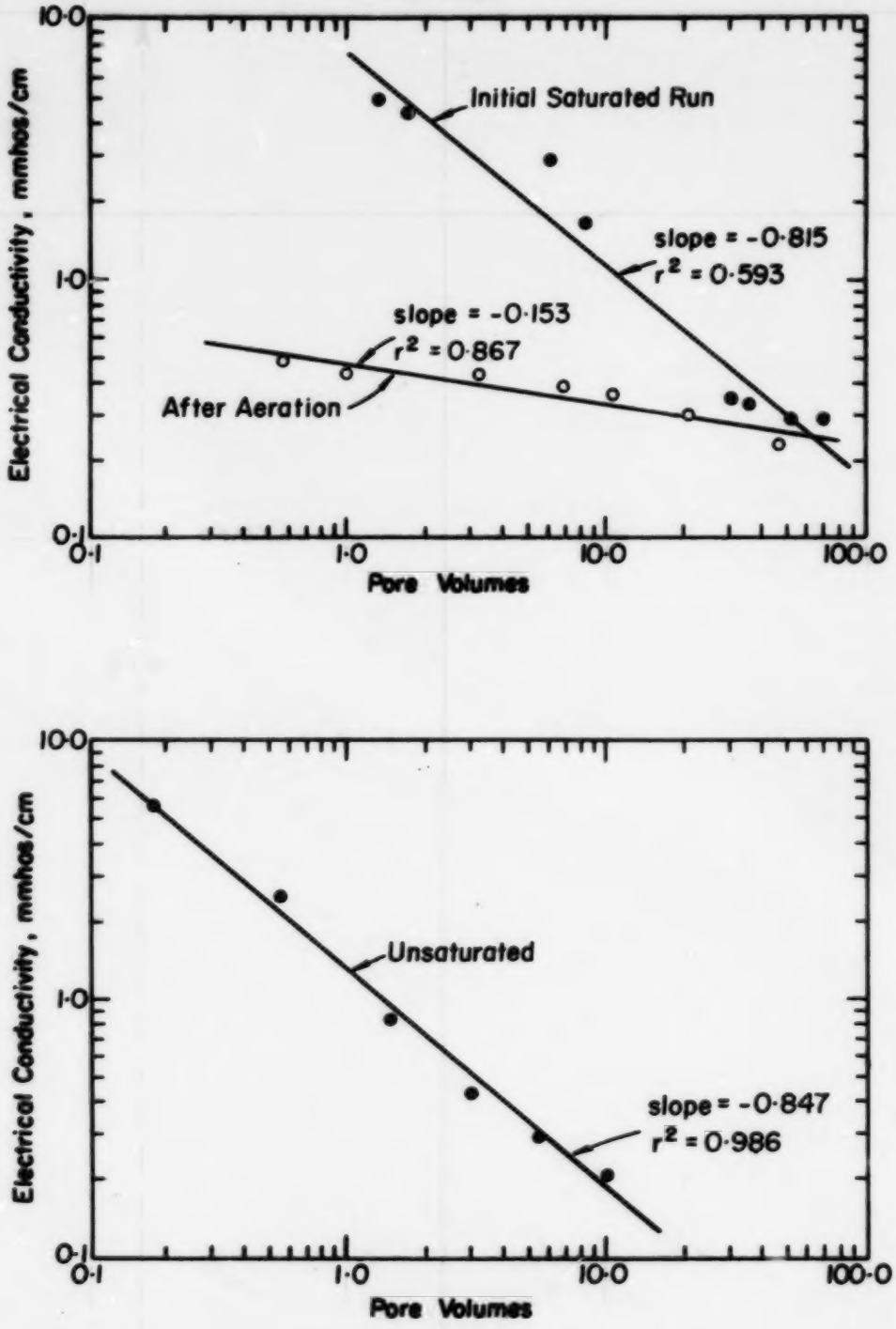



Figure 4. Leaching characteristics of Colony naturally leached shale.

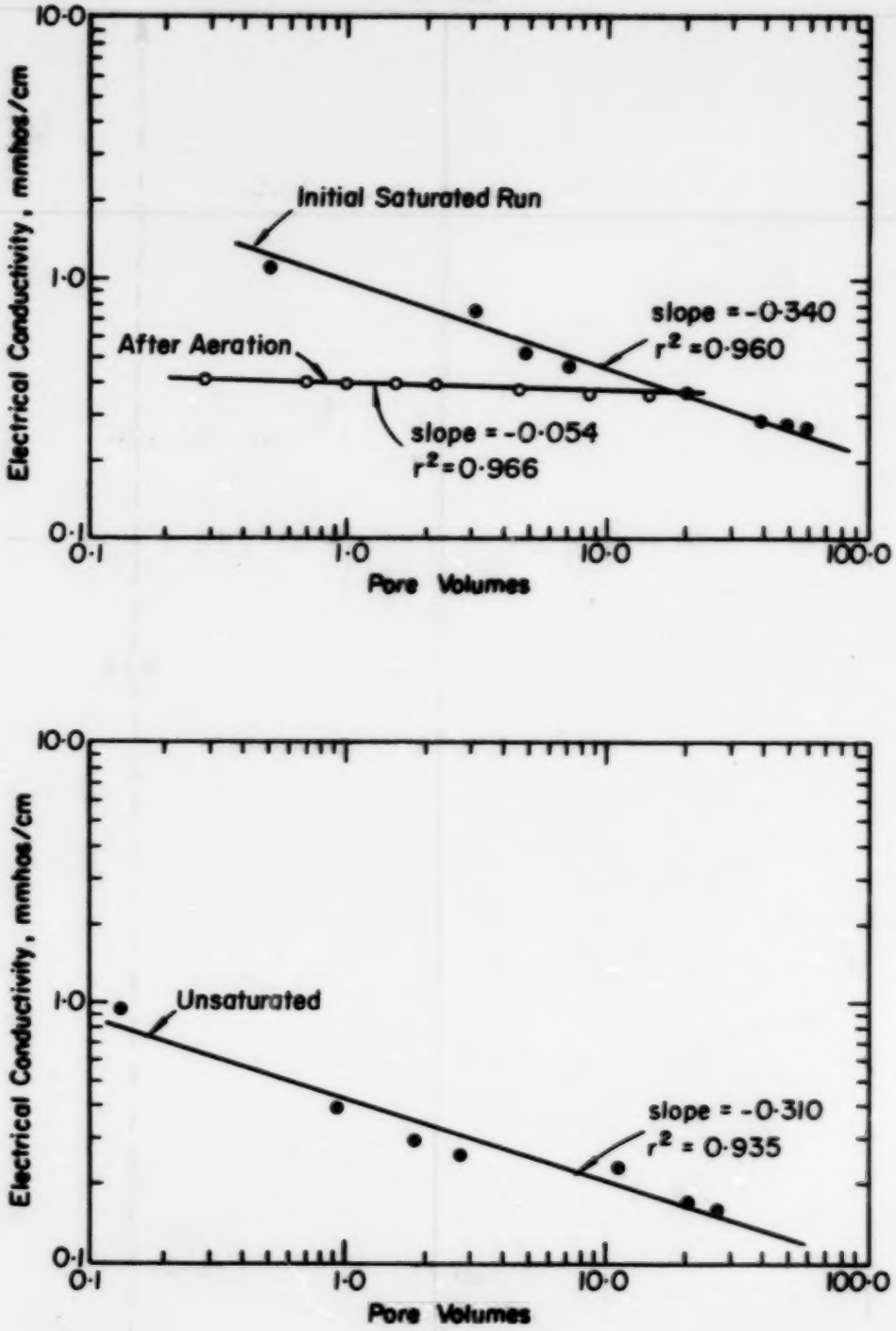



Figure 5. Leaching characteristics of Union naturally retorted shale.

All of the EC versus pore volume data were fit satisfactorily with an equation of the type

$$EC = EC_m \left( \frac{PV}{PV_m} \right)^{-\alpha}, \quad PV \geq PV_m$$

where $EC_m$ is the maximum electrical conductivity observed and $PV_m$ is the corresponding volume of effluent expressed in pore volumes (PV). This equation does not apply after the EC of the leachate begins to stabilize following the removal of the most readily soluble materials. For the USBM, Colony, and C-a composite raw shales, the exponent $\alpha$ varied between 0.8 and 1.1. However, for the C-a R-5/Mahogany shale this leaching index was between 0.4 and 0.5. The chemical composition of the leachate from the R-5/Mahogany shale was also substantially different from that of the other three raw shales; the total dissolved solids being significantly greater, sodium concentrations being disproportionately greater, and a very small quantity of magnesium being present in the leachate.

## TRACE ELEMENTS

The results from the eight materials tested were divided into two groups; those for the 4 mined shales and those for the 4 materials that have been exposed to leaching and weathering under natural circumstances. The maximum concentrations of each trace element that were observed for each group are presented in Table 4. This presentation assists in gaining an overview of the degree to which trace element concentrations in leachate from the mined shales differ from those obtained from materials that might reasonably be expected to represent background conditions.

In view of the range of values that results entirely from material variability, variable leaching rates, and analytical error, only the concentrations of Al, B, F, Mo, Pb, and Zn in Table 4 are significantly elevated in the mined shales relative to that in the background materials. In the case of zinc, only the USBM raw shale produced concentrations in excess of the maximum observed in the background materials. The elevated zinc concentrations from the USBM material does not appear to be spurious, as relatively high concentrations were observed in a number of samples.

The maximum concentration of Mo was observed in the initial sample from the unsaturated leaching of the C-a R-5/Mahogany material. The subsequent sample collected at 0.88 PV of effluent contained a much reduced quantity of Mo but still a relatively high value. The Mo concentration in the initial sample from the saturated column of R-5/Mahogany material was not obtained due to analytical difficulties. However, the C-a composite material in both the saturated and unsaturated experiments showed initial Mo concentrations that are approximately twice those obtained in the other materials. It is believed that subsequent leaching studies of raw shale from the C-a site

TABLE 4. COMPARISON OF TRACE ELEMENT CONCENTRATIONS FROM RAW MINED SHALES WITH THOSE FROM SOILS AND PREVIOUSLY EXPOSED SHALES

| Element | Raw Mined Shales | | Soils & Previously Exposed Shales | | Drinking Water Criteria |
|---|---|---|---|---|---|
| | Max. Conc. Observed mg/l | Test Yielding Max. Conc. | Max. Conc. Observed mg/l | Test Yielding Max. Conc. | |
| Al | 7.54 | USBM, Unsaturated | 0.37 | Colony Soil | ---- |
| As | <0.005 | ---- | <0.005 | ---- | 0.05 |
| B | 43 | USBM, #2 Saturated | 0.99 | C-b Soil | ---- |
| Ba | 0.48 | Colony Raw, #2 Sat. | 0.50 | Colony Nat. | 1.0 |
| Be | <0.025 | ---- | <0.025 | ---- | ---- |
| Cr | 0.68 | USBM, #1 Saturated | 0.71 | Union Nat. Ret. | 0.05 |
| Cu | 0.69 | C-a R-5/Mahog., Unsat. | 0.38 | Colony Soil | 1.0 |
| F | 75 | USBM, #1 Saturated | 25 | C-b Soil | 1.8 |
| Fe | 1.8 | USBM, #1 Resaturated | 0.52 | Colony Soil | 0.30 |
| Hg | 0.0035 | USBM, #2 Saturated | <0.0005 | ---- | 0.002 |
| Li | 3.1 | USBM, #2 Saturated | 0.51 | Union Nat. Ret. | ---- |
| Mn | 3.2 | USBM, #2 Saturated | 0.97 | Colony Soil | 0.05 |
| Mo | 5.18 | C-a R-5/Mahog., Unsat. | 0.84 | Colony Soil | ---- |
| Ni | 0.60 | USBM, #2 Saturated | 0.075 | C-b Soil | ---- |
| Pb | 1.9 | USBM, #1 Saturated | 0.38 | Colony Soil | 0.05 |
| Se | <0.01 | ---- | <0.01 | ---- | 0.01 |
| Si | 23.28 | C-a R-5/Mahog., Unsat. | 20.7 | C-b Soil | ---- |
| Sn | 1.28 | USBM, #2 Saturated | 1.37 | Colony Soil | ---- |
| Zn | 6.8 | USBM, #1 Saturated | 0.65 | Colony Soil | 5.0 |

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should include analyses for Mo to verify or disprove the indications of elevated Mo obtained in this study.

Concentrations of Al in leachate from both saturated runs and the unsaturated experiment on USBM raw shale were significantly elevated relative to the background materials. Elevated concentrations in the C-a R-5/Mahogany leachate were also observed. The greatest concentrations of Al for each material were found in the leachates from either the aerated columns or the unsaturated columns. No consistent relationship between the Al concentration and leachate volume was observed. The average concentration of Al in the USBM saturated runs was 1.76 mg/l, which compares to 3.71 mg/l obtained for the same material by averaging the concentrations from the aerated and unsaturated experiments. These data suggest that Al is produced into the water in the greatest quantites when aerated conditions exist.

The concentrations of F and B observed in this study are of the same order as those measured by others (Runnells, et al., 1979). Boron concentrations in the leachates obtained at small throughput volumes from USBM, Colony, and C-a composite were all substantially greater than the maximum value observed in the background materials that were tested. Boron concentrations in leachates from C-a R-5/Mahogany were all less than the maximum value obtained in the soils and previously exposed materials. The largest concentrations of B were consistently measured in leachates from the USBM raw shale. The other mined shales exhibited B concentrations much less than the USBM material. A trend toward decreasing concentration of B with increasing leachate volume was observed as shown in Figure 6. Because of the large differences in concentrations for different materials, the actual concentrations were divided by the maximum observed value so that all data could be shown conveniently on a single figure. The data in Figure 6 suggest that the Boron concentrations will be reduced to 10 percent of the maximum value by approximately 5 PV of continuous leaching. Aeration following the first leaching did not cause the B concentration to recover significantly.

The maximum concentrations of F were observed in the USBM experiments, but the F concentrations in the background materials are also relatively high. In these leaching tests, the concentration of F was generally greatest in samples obtained at small throughput volumes, although this was not uniformly true. Figure 7 shows the leaching trend for F from USBM and R-5/Mahogany materials. These data show a relatively stable concentration of F of 20-25 mg/l after an initial reduction from a maximum of 75 mg/l for the USBM raw shale. Concentrations of F in leachate from the same column after 108 days of drainage and aeration did not differ significantly from the stable values obtained in the first cycle of leaching.

With the exception of the USBM material, the more-or-less stable concentrations of F obtained in the mined raw shales were between 1 and 10 mg/l. (Figure 8). The stable concentrations in both materials from the C-a site were found to be about equal to that for the soils. The Colony naturally leached shale and the Colony mined raw shale showed approximately equal F concentrations over most of the range of leachate volumes (Figure 8), even though the naturally leached material had previously been subjected to countless leaching cycles in its natural environment.

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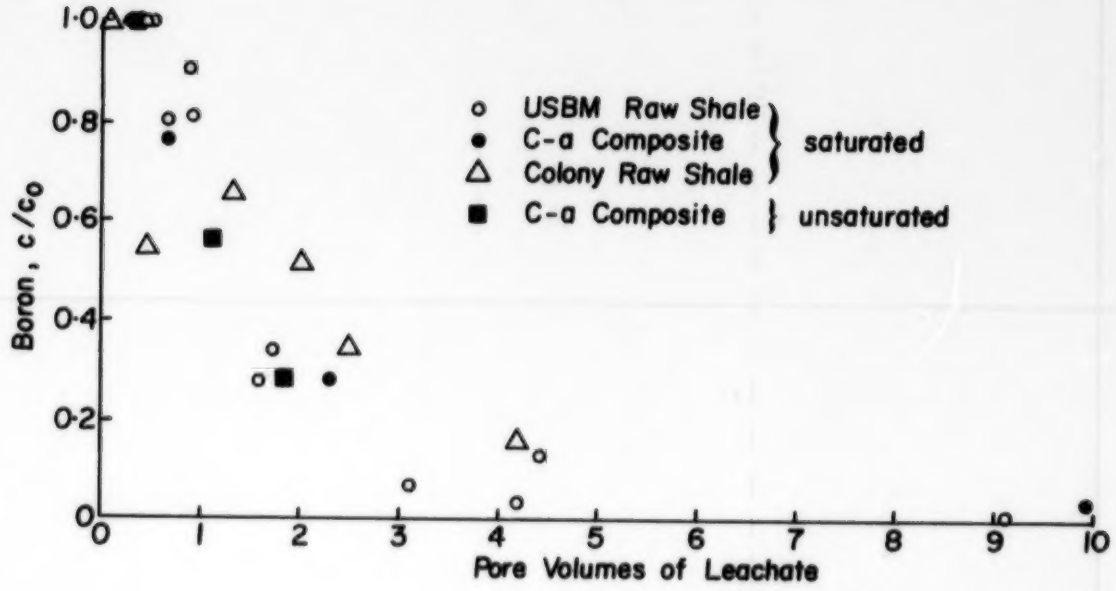


Figure 6. Leaching of Boron from raw shale.

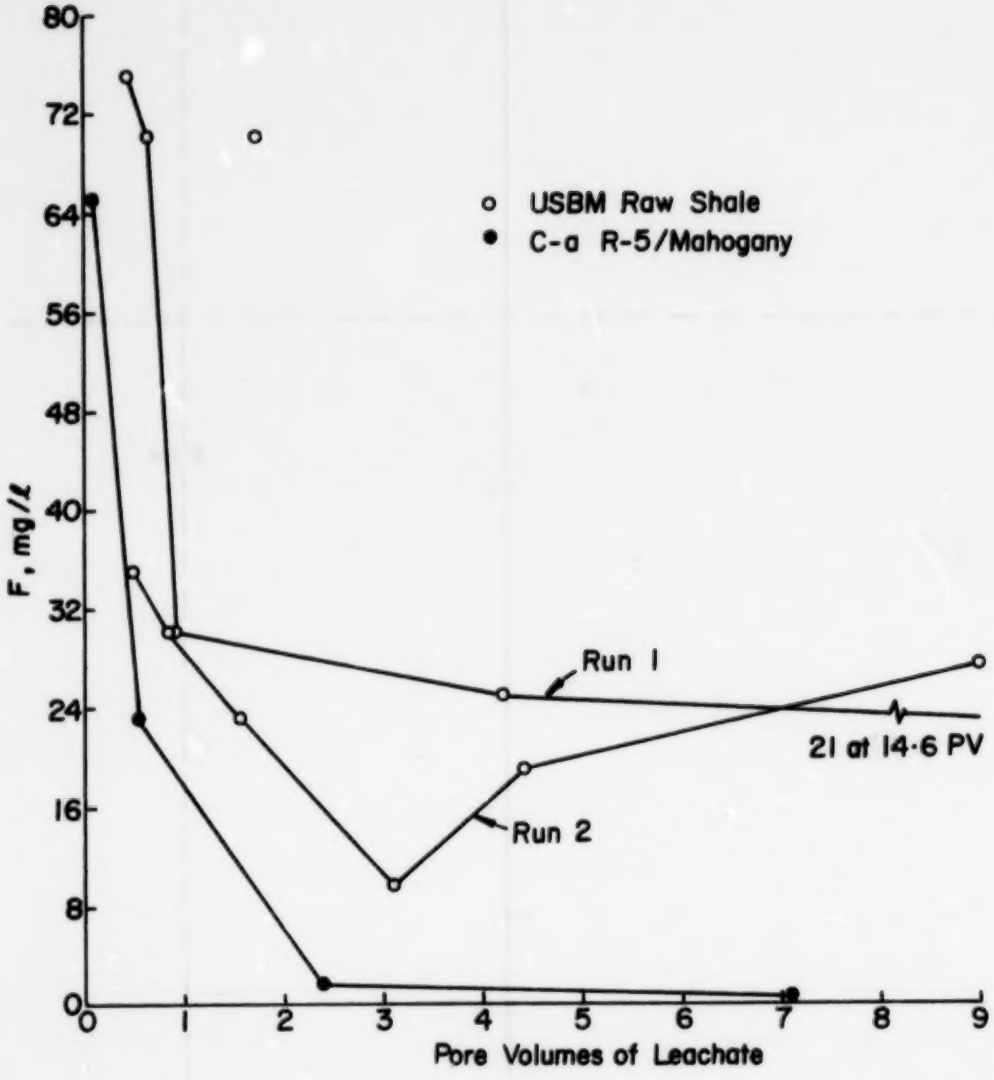


Figure 7. Leaching of F from raw shale. (Saturated columns)

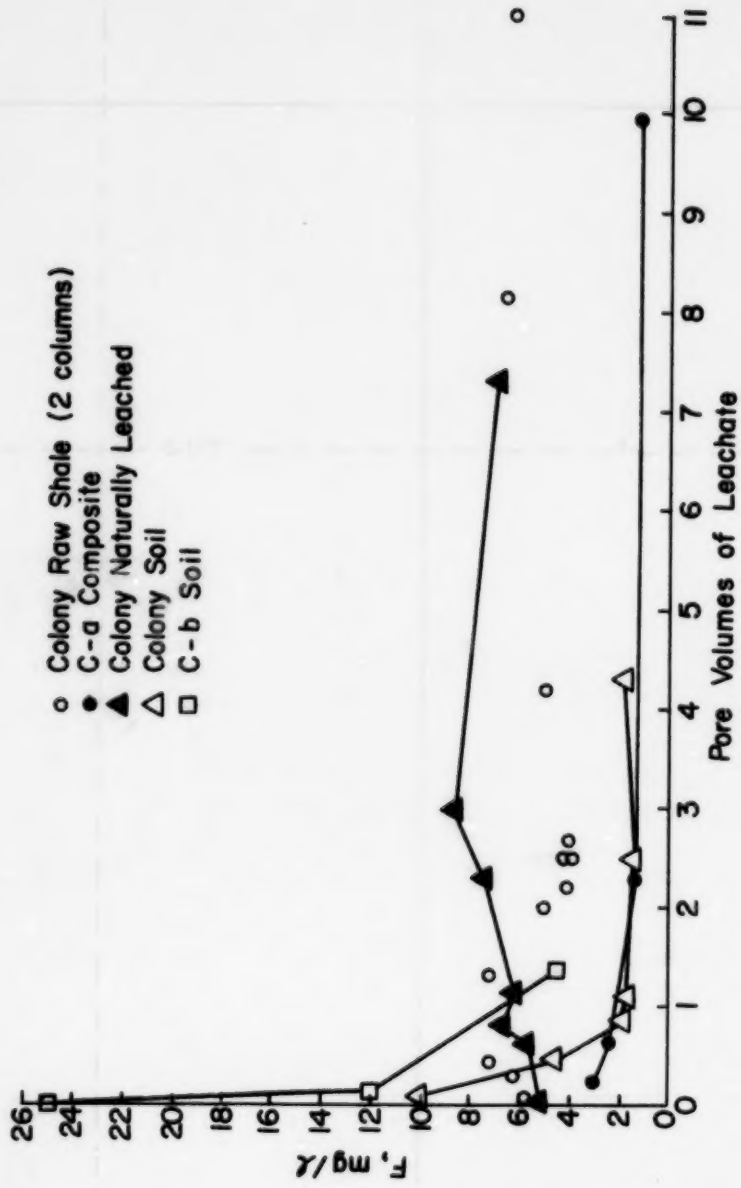


Figure 8. Leaching of F from raw shale. (Saturated columns)

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# APPENDIX

## TABULATED CHEMICAL DATA AND GRAIN SIZE DISTRIBUTIONS

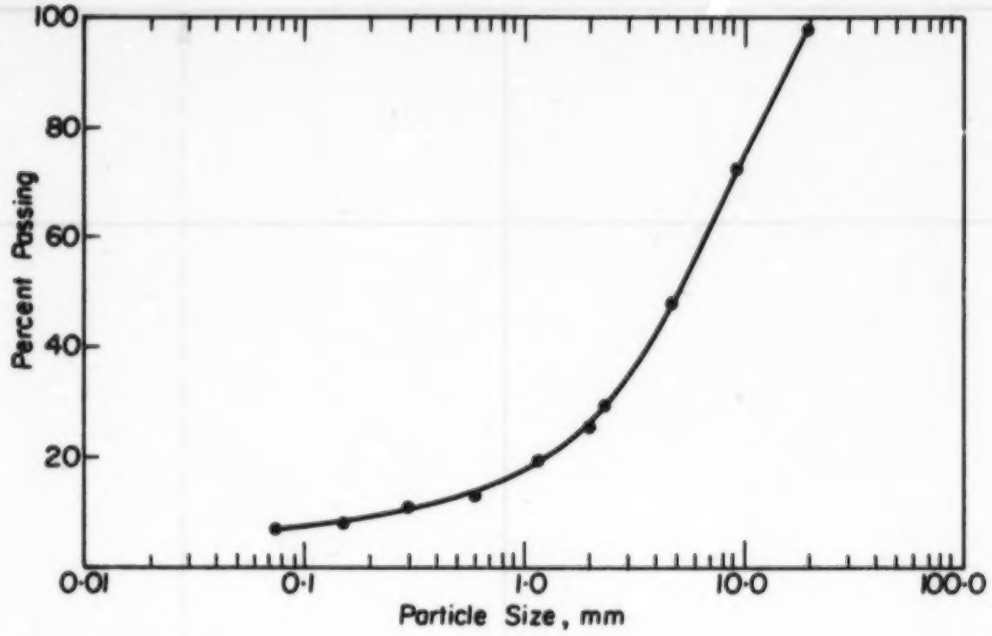



Figure A-1. Particle size distribution for USBM raw shale.

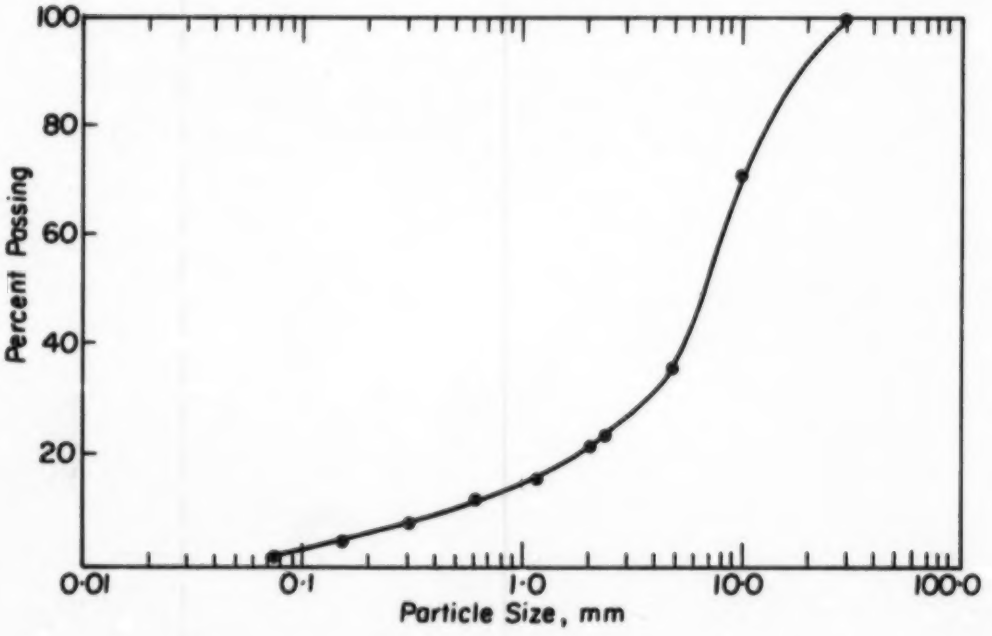



Figure A-2. Particle size distribution for Colony raw shale.

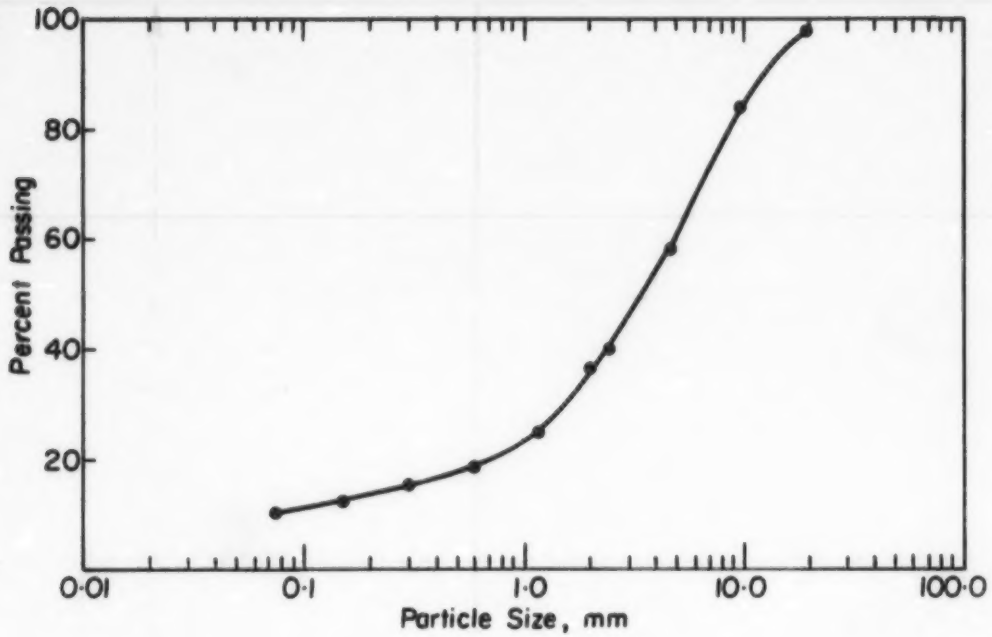



Figure A-3. Particle size distribution for C-a Composite raw shale.

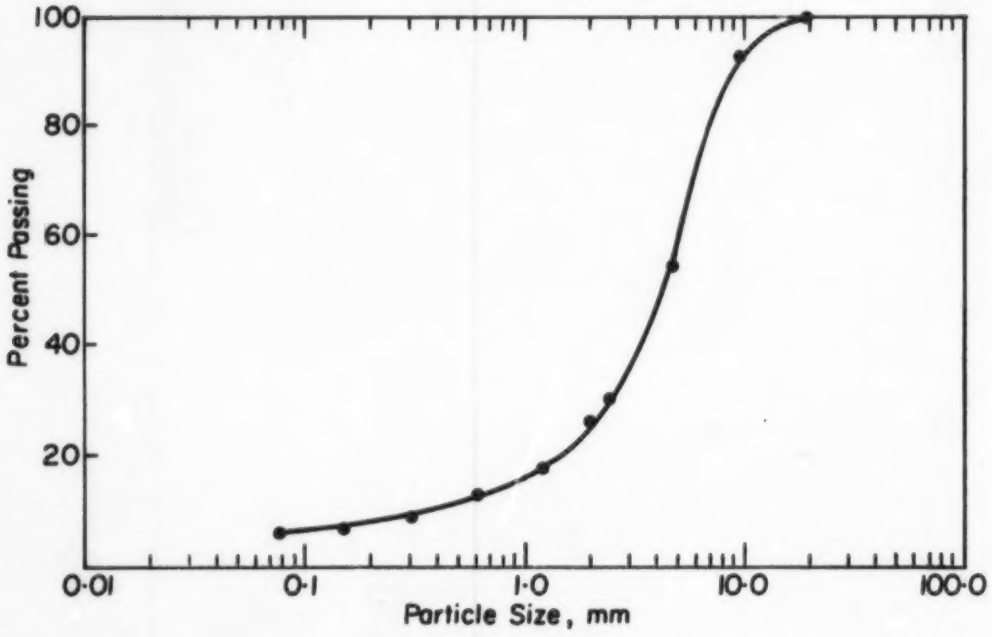



Figure A-4. Particle size distribution for C-a R-5/Mahogany raw shale.

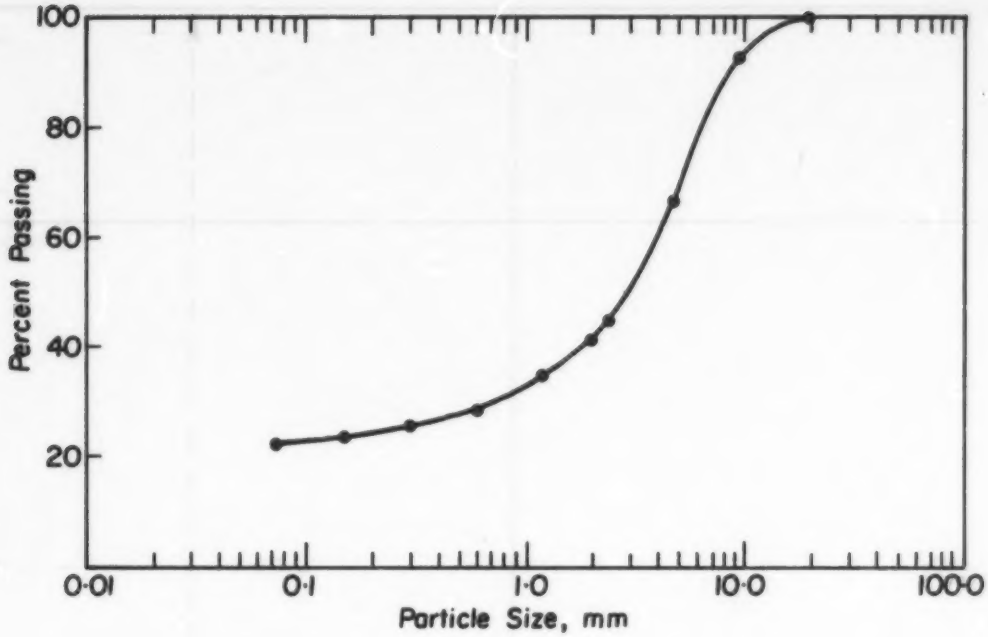



Figure A-5. Particle size distribution for Union naturally retorted shale.

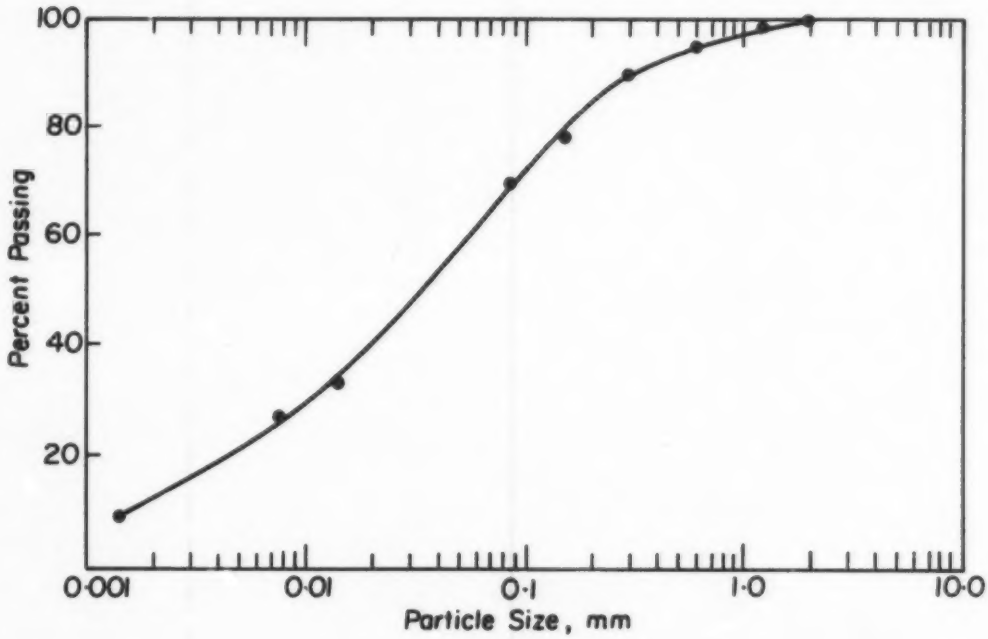



Figure A-6. Particle size distribution for C-b soil.

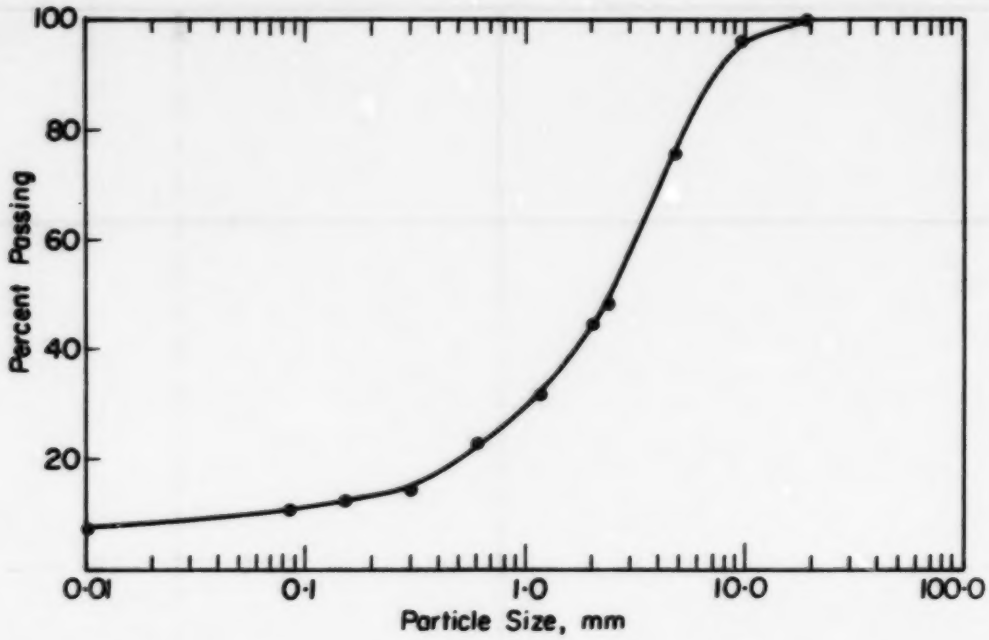
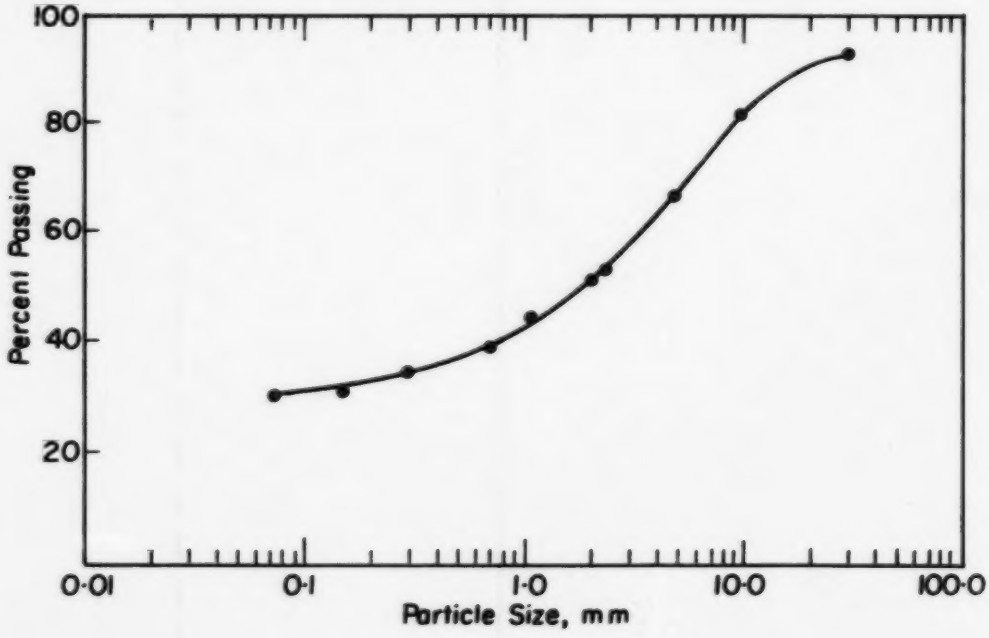



Figure A-7. Particle size distribution for Colony naturally leached shale.




A-8. Particle size distribution for Colony soil.

TABLE A-1 USBM RAW SHALE - RUN #1 (SATURATED)

| Parameter | Units | Volume of Effluent | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0.43 PV | 0.65 PV | 0.90 PV | 1.73 PV | 4.18 PV | 14.61 PV |
| Al | mg/l | 1.85 | 0.75 | 5.4 | 1.55 | 0.80 | 0.34 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 29.5 | 23.5 | 24.0 | 10.0 | 0.95 | 0.24 |
| Ba | " | 0.17 | 0.15 | 0.16 | 0.10 | 0.10 | 0.07 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 520 | 550 | 600 | 500 | 220 | 36 |
| Cl | " | 430 | 360 | 250 | 130 | 5.0 | <1.0 |
| $CO_3$ | " | 0.10 | 0.30 | 0.17 | 0.47 | 0.15 | 0.17 |
| Cr | " | 0.55 | 0.37 | 0.68 | 0.125 | <0.025 | <0.025 |
| Cu | " | 0.22 | 0.17 | 0.07 | <0.025 | <0.025 | <0.025 |
| EC | µmhos/cm | 11000 | 9000 | 9000 | 4500 | 1100 | 280 |
| F | mg/l | 75 | 70 | 30 | 70 | 25 | 21 |
| Fe | " | 0.75 | 0.31 | 0.20 | 0.39 | 0.01 | 0.06 |
| $HCO_3$ | " | 243 | 247 | 229 | 270 | 122 | 83.1 |
| Hg | " | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| K | " | 19 | 16 | 18 | 10 | 2.1 | 1.1 |
| Li | " | 2.4 | 2.5 | 2.6 | 1.6 | 0.11 | 0.02 |
| Mg | " | 1050 | 370 | 680 | 220 | 12.2 | 6.7 |
| Mn | " | 2.9 | 2.6 | 2.65 | 1.68 | 0.23 | 0.075 |
| MO | " | 0.87 | 0.83 | 0.45 | 0.475 | 0.17 | 0.09 |
| Na | " | 1430 | 600 | 1120 | 400 | 65 | <25 |
| Ni | " | 0.48 | 0.48 | 0.53 | 0.33 | 0.04 | <0.025 |
| $NO_3$ | " | <25 | <25 | <25 | <25 | <6.25 | <1.25 |
| Pb | " | 0.57 | 0.41 | 1.9 | 0.21 | 0.08 | <0.04 |
| pH | --- | 6.8 | 7.3 | 7.1 | 7.5 | 7.3 | 7.5 |
| Se | mg/l | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Si | " | 7.5 | 3.9 | 7.6 | 6.2 | 3.4 | 1.65 |
| Sn | " | 1.1 | 1.18 | 1.12 | 0.51 | 0.038 | <0.025 |
| $SO_4$ | " | | | | | | |
| TDS | " | 12600 | 13300 | 10500 | 11900 | 1300 | 103 |
| TOC | " | 199 | 228 | 103 | 85 | 26 | 11 |
| Zn | " | 5.2 | 4.9 | 6.8 | 3.0 | 0.39 | 0.02 |

Source: Saline Zone of the Green River Formation - USBM, Horse Draw site
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 5 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 5400 $cm^3$
Mean Leaching Rate: 0.022 PV per hour
Mean Residence Time: 46 hours

TABLE A-2 USBM RAW SHALE - RUN #2 (SATURATED)

| Parameter | Units | Volume of Effluent | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0.48 PV | 0.86 PV | 1.56 PV | 3.08 PV | 4.41 PV | 9.11 PV |
| Al | mg/l | 1.7 | 1.8 | 3.72 | 1.30 | 0.85 | 1.05 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 43.0 | 39.0 | 12.0 | 2.7 | 5.5 | 0.37 |
| Ba | " | 0.16 | 0.14 | 0.11 | 0.10 | 0.10 | 0.11 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 750 | 700 | 530 | 460 | 550 | 40 |
| Cl | " | 560 | 410 | 95 | 8.0 | 32 | 3.8 |
| $CO_3$ | " | 0.10 | 0.17 | 0.29 | 0.77 | 1.10 | 0.19 |
| Cr | " | 0.45 | 0.46 | 0.20 | <0.025 | <0.025 | <0.025 |
| Cu | " | 0.25 | 0.30 | 0.045 | <0.025 | <0.025 | 0.070 |
| EC | µmhos/cm | 13000 | 11000 | 4500 | 2700 | 2500 | 420 |
| F | mg/l | 35 | 30 | 23 | 9.5 | 19 | 27.5 |
| Fe | " | 1.5 | 0.85 | 0.06 | 0.01 | 1.6 | 0.09 |
| $HCO_3$ | " | 287 | 321 | 257 | 172 | 257 | 90 |
| Hg | " | 0.0035 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| K | " | 22 | 10 | 8.7 | 5.9 | 4.5 | 1.2 |
| Li | " | 3.1 | 2.9 | 1.6 | 0.34 | 0.18 | 0.02 |
| Mg | " | 1350 | 1350 | 270 | 40 | 45 | 8.0 |
| Mn | " | 3.2 | 3.02 | 1.5 | 0.7 | 0.5 | 0.13 |
| MO | " | 0.85 | 0.90 | 0.52 | 0.27 | 0.235 | 0.19 |
| Na | " | 2100 | 2000 | 480 | 130 | 200 | 25 |
| Ni | " | 0.60 | 0.50 | 0.28 | 0.11 | <0.025 | <0.025 |
| $NO_3$ | " | 40 | --- | <10 | 5.0 | 4.0 | 5.0 |
| Pb | " | 0.47 | 0.47 | 0.35 | 0.15 | 0.05 | 0.06 |
| pH | --- | 6.8 | 7.0 | 7.2 | 7.9 | 7.9 | 7.6 |
| Se | mg/l | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Si | " | 5.85 | 6.25 | 9.7 | 4.75 | 5.0 | 2.67 |
| Sn | " | 1.28 | 1.12 | 0.47 | 0.11 | 0.10 | 0.11 |
| $SO_4$ | " | | | | | | |
| TDS | " | 14850 | 13000 | 5050 | 2700 | 1950 | 70 |
| TOC | " | 41 | 130 | 109 | 42 | 95 | 15 |
| Zn | " | 6.0 | 6.2 | 3.1 | 0.55 | 0.02 | 0.01 |

Source: Saline Zone of the Green River Formation - USBM, Horse Draw Site
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 5 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 5400 $cm^3$
Mean Leaching Rate: 0.014 PV per hour
Mean Residence Time: 74 hours

TABLE A-3 COLONY RAW SHALE - RUN #1 (SATURATED)

| Parameter | Units | Volume of Effluent | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0.061 PV | 0.45 PV | 1.32 PV | 1.99 PV | 2.48 PV | 4.20 PV | 11.00 PV |
| Al | mg/l | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 0.75 | 1.48 | 1.79 | 1.40 | 0.94 | 0.43 | 0.36 |
| Ba | " | 0.34 | 0.29 | 0.38 | 0.26 | 0.22 | 0.16 | 0.20 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 1110 | 1510 | 830 | 700 | 530 | 200 | 77 |
| Cl | " | 8.5 | 22.0 | 8.5 | 5.0 | 3.7 | 3.0 | 1.3 |
| $CO_3$ | " | 0.18 | 0.39 | 1.4 | 1.4 | 1.6 | 1.2 | 0.18 |
| Cr | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Cu | " | 0.16 | 0.34 | 0.12 | <0.025 | <0.025 | <0.025 | <0.025 |
| EC | µmhos/cm | 4200 | 4600 | 3100 | 2600 | 2300 | 900 | 460 |
| F | mg/l | 5.7 | 7.2 | 7.2 | 5.0 | 4.2 | 5.0 | 6.3 |
| Fe | " | <0.03 | <0.03 | 0.89 | 0.83 | 0.47 | 0.15 | <0.03 |
| $HCO_3$ | " | 266 | 304 | 558 | 447 | 385 | 250 | 178 |
| Hg | " | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| K | " | 19 | 18 | 11 | 6.7 | 4.9 | 2.3 | 3.1 |
| Li | " | 0.098 | 0.085 | 0.111 | 0.151 | 0.145 | 0.100 | 0.075 |
| Mg | " | 72 | 120 | 140 | 88 | 50 | 18 | 14 |
| Mn | " | 0.24 | 0.28 | 1.64 | 2.74 | 1.91 | 0.82 | 0.17 |
| MO | " | 0.16 | 0.11 | 0.27 | 0.35 | 0.31 | 0.36 | 0.65 |
| Na | " | 100 | 130 | 80 | 52 | 66 | 15 | 17 |
| Ni | " | 0.087 | 0.080 | <0.05 | <0.05 | 0.07 | <0.05 | <0.05 |
| $NO_3$ | " | 25.0 | 25.0 | <2.5 | <2.5 | <2.5 | <2.5 | <2.5 |
| Pb | " | 0.12 | <0.05 | 0.20 | 0.64 | 0.19 | 0.095 | 0.08 |
| pH | --- | 7.06 | 7.34 | 7.62 | 7.72 | 7.85 | 7.89 | 7.23 |
| Se | mg/l | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Si | " | 2.95 | 9.47 | 10.58 | 7.39 | 5.89 | 4.54 | 4.22 |
| Sn | " | 0.24 | 0.48 | 0.47 | 0.33 | 0.27 | 0.17 | 0.12 |
| $SO_4$ | " | | | | | | | |
| TDS | " | 4590 | 6000 | 3250 | 2860 | 2400 | 770 | 400 |
| TOC | " | | | | | | | |
| Zn | " | 0.29 | 0.62 | 0.58 | 0.50 | 0.31 | 0.06 | 0.04 |

Source: Mine Stock Pile - Parachute Creek
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 6.7 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 4290 $cm^3$
Mean Leaching Rate: 0.010 PV per hour
Mean Residence Time: 103 hours

TABLE A-4 COLONY RAW SHALE - RUN #2 (SATURATED)

| Parameter | Units | Volume of Effluent | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0.13 PV | 0.30 PV | 2.21 PV | 2.48 PV | 2.69 PV | 8.14 PV | 12.54 PV |
| Al | mg/l | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| As | " | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 |
| B | " | 0.44 | 2.2 | 1.25 | 1.2 | 1.08 | 0.2 | 0.2 |
| Ba | " | 0.48 | 0.32 | 0.25 | 0.25 | 0.10 | 0.21 | 0.19 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 760 | 1550 | 730 | 620 | 640 | 51 | 44 |
| Cl | " | 8.7 | 8.0 | 8.0 | 8.5 | 4.0 | 1.3 | 1.4 |
| $CO_3$ | " | 0.11 | 0.03 | 0.60 | 0.57 | 1.1 | 0.49 | 0.94 |
| Cr | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Cu | " | 0.37 | 0.41 | 0.096 | 0.064 | <0.025 | <0.025 | <0.025 |
| EC | µmhos/cm | 3200 | 5400 | 2900 | 2700 | 2500 | 290 | 330 |
| F | mg/l | 4.0 | 6.2 | 4.0 | 4.0 | 4.0 | 6.6 | 5.5 |
| Fe | " | <0.03 | <0.03 | 0.03 | 0.05 | 0.04 | <0.03 | <0.03 |
| $HCO_3$ | " | 150 | 50 | 234 | 215 | 223 | 111 | 105 |
| Hg | " | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| K | " | 59 | 18 | 8.0 | 7.4 | 3.1 | 1.7 | 2.3 |
| Li | " | 0.068 | 0.080 | 0.065 | 0.064 | 0.062 | 0.032 | 0.035 |
| Mg | " | 40 | 140 | 85 | 71 | 55 | 7.2 | 7.4 |
| Mn | " | 0.093 | 0.26 | 1.16 | 1.20 | 1.26 | 0.20 | 0.125 |
| MO | " | 0.13 | 0.29 | 0.23 | 0.28 | 0.24 | 0.23 | 0.45 |
| Na | " | 90 | 145 | 93 | 71 | 60 | 10 | 14 |
| Ni | " | 0.064 | 0.10 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| $NO_3$ | " | 3.5 | <2.5 | <2.5 | <2.5 | <2.5 | <0.4 | 0.9 |
| Pb | " | 0.14 | 0.27 | <0.05 | 0.11 | <0.05 | 0.052 | <0.05 |
| pH | --- | 7.09 | 7.06 | 7.64 | 7.65 | 7.92 | 7.87 | 8.18 |
| Se | mg/l | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Si | " | 4.75 | 9.11 | 5.02 | 4.44 | 4.30 | 2.30 | 2.18 |
| Sn | " | 0.26 | 0.67 | 0.44 | 0.43 | 0.41 | 0.13 | 0.12 |
| $SO_4$ | " | | | | | | | |
| TDS | " | 3660 | 7160 | 3380 | 3140 | 2840 | 310 | 230 |
| TOC | " | | | | | | | |
| Zn | " | 0.10 | 0.52 | 0.68 | 0.54 | <0.04 | <0.04 | 0.53 |

Source: Mine Stock Pile - Parachute Creek
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 6.7 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 4290 $cm^3$
Mean Leaching Rate: 0.011 PV per hour
Mean Residence Time: 90 hours

TABLE A-5 C-a COMPOSITE - RUN #1 (SATURATED)

| Parameter | Units | Volume of Effluent | | | |
|---|---|---|---|---|---|
| | | 0.25 PV | 0.64 PV | 2.29 PV | 9.96 PV |
| Al | mg/l | <0.05 | <0.05 | <0.05 | <0.05 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 1.45 | 1.10 | 0.40 | 0.06 |
| Ba | " | 0.093 | 0.046 | 0.051 | 0.027 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 425 | 370 | 100 | 18 |
| Cl | " | 38 | 6.8 | 0.3 | 0.3 |
| $CO_3$ | " | <1.0 | <1.0 | <1.0 | <1.0 |
| Cr | " | <0.025 | <0.025 | <0.025 | <0.025 |
| Cu | " | <0.025 | 0.060 | <0.025 | <0.025 |
| EC | µmhos/cm | 8200 | 5600 | 850 | 170 |
| F | mg/l | 3.0 | 2.4 | 1.4 | 1.3 |
| Fe | " | <0.05 | <0.05 | <0.05 | <0.05 |
| $HCO_3$ | " | 239 | 180 | 165 | 87 |
| Hg | " | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K | " | 34 | 10 | 2.0 | 0.4 |
| Li | " | 0.68 | 0.42 | 0.08 | 0.03 |
| Mg | " | 16 | 415 | 48 | 6.9 |
| Mn | " | <0.05 | 0.24 | 0.062 | <0.05 |
| MO | " | 2.2 | 0.9 | 0.475 | 0.100 |
| Na | " | 740 | 250 | 33 | 5.9 |
| Ni | " | <0.05 | 0.09 | <0.05 | <0.05 |
| $NO_3$ | " | 140 | 17 | <0.5 | 0.5 |
| Pb | " | 0.204 | 0.20 | 0.075 | <0.05 |
| pH | --- | 7.25 | 7.69 | 7.99 | 7.93 |
| Se | mg/l | <0.005 | <0.005 | <0.005 | <0.005 |
| Si | " | 10.0 | 10.0 | 10.9 | 5.8 |
| Sn | " | --- | --- | --- | --- |
| $SO_4$ | " | | | | |
| TDS | " | 9150 | 6410 | 1580 | 440 |
| TOC | " | | | | |
| Zn | " | 0.50 | 1.5 | 0.30 | 0.05 |

Source: Composite of Raised Bore Cuttings From G Level In R-5 Zone to Surface - Lease Tract C-a
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 3.5 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 6344 $cm^3$
Mean Leaching Rate: 0.015 PV per hr.
Mean Residence Time: 67 hours

TABLE A-6 C-a R-5 / MAHOGANY - RUN #1 (SATURATED)

| Parameter | Units | Volume of Effluent | | | |
|---|---|---|---|---|---|
| | | 0.062 PV | 0.519 PV | 2.38 PV | 7.10 PV |
| Al | mg/l | --- | 0.70 | 0.30 | 2.00 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 0.59 | 0.035 | <0.025 | <0.025 |
| Ba | " | --- | 0.11 | 0.088 | 0.16 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 1430 | 375 | 900 | 240 |
| Cl | " | 125 | 45 | 3.8 | 1.9 |
| $CO_3$ | " | 175 | 312 | 346 | 174 |
| Cr | " | --- | <0.025 | <0.025 | <0.025 |
| Cu | " | 0.33 | 0.16 | <0.025 | <0.025 |
| EC | µmhos/cm | 20000 | 9600 | 3400 | 3400 |
| F | mg/l | 65 | 23 | 1.9 | 0.8 |
| Fe | " | <0.05 | <0.05 | <0.05 | <0.05 |
| $HCO_3$ | " | 22 | 9.4 | 7.7 | 3.0 |
| Hg | " | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K | " | 280 | 180 | 50 | 16 |
| Li | " | 0.11 | 0.07 | 0.06 | 0.03 |
| Mg | " | --- | <0.7 | <0.7 | <0.7 |
| Mn | " | 0.35 | <0.05 | <0.05 | <0.05 |
| MO | " | --- | 0.20 | 0.225 | 0.10 |
| Na | " | 3600 | 1700 | 310 | 60 |
| Ni | " | --- | 0.085 | <0.05 | <0.05 |
| $NO_3$ | " | 95 | 40 | 9.0 | 4.0 |
| Pb | " | --- | 0.15 | <0.05 | 0.12 |
| pH | --- | 11.14 | 11.75 | 11.88 | 11.98 |
| Se | mg/l | <0.005 | <0.005 | <0.005 | <0.005 |
| Si | " | --- | 5.94 | 1.65 | 1.20 |
| Sn | " | --- | --- | --- | --- |
| $SO_4$ | " | | | | |
| TDS | " | 19000 | 6880 | 1340 | 1160 |
| TOC | " | | | | |
| Zn | " | <0.01 | <0.01 | 0.03 | 0.08 |

Source: R-5/Mahogany Zone - Lease Tract C-a
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 4.2 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 7463 $cm^3$
Mean Leaching Rate: 0.0093 PV per hr.
Mean Residence Time: 108 hours

TABLE A-7 C-b SOIL - RUN #1 (SATURATED)

| Parameter | Units | Volume of Effluent | | | |
|---|---|---|---|---|---|
| | | 0.0084 PV | 0.13 PV | 0.46 PV | 1.35 PV |
| Al | mg/l | <0.05 | <0.05 | <0.05 | <0.05 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 0.65 | 0.985 | 0.830 | 0.870 |
| Ba | " | 0.169 | 0.240 | 0.073 | 0.038 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 330 | 75 | 11 | 6.5 |
| Cl | " | 520 | 53 | 2.4 | 1.8 |
| $CO_3$ | " | --- | 1.3 | 1.0 | 8.8 |
| Cr | " | 0.069 | <0.025 | <0.025 | <0.025 |
| Cu | " | 0.28 | 0.25 | 0.075 | <0.025 |
| EC | µmhos/cm | --- | 3000 | 900 | 840 |
| F | mg/l | 25 | 12 | 4.6 | 4.5 |
| Fe | " | 0.17 | 0.42 | 0.38 | 0.10 |
| $HCO_3$ | " | --- | 846 | 509 | 481 |
| Hg | " | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K | " | 22 | 21 | 2.5 | 1.3 |
| Li | " | 0.08 | 0.05 | 0.02 | 0.02 |
| Mg | " | 145 | 35 | 3.8 | 2.6 |
| Mn | " | 0.075 | 0.16 | <0.05 | <0.05 |
| MO | " | 0.125 | 0.43 | 0.10 | <0.05 |
| Na | " | 2050 | 840 | 230 | 210 |
| Ni | " | <0.05 | 0.075 | <0.05 | <0.05 |
| $NO_3$ | " | 30 | 15 | 1.6 | 1.4 |
| Pb | " | 0.31 | 0.26 | 0.12 | 0.07 |
| pH | --- | 8.01 | 7.43 | 7.54 | 8.49 |
| Se | mg/l | <0.005 | <0.005 | <0.005 | <0.005 |
| Si | " | 11.0 | 20.7 | 11.8 | 11.7 |
| Sn | " | --- | --- | --- | --- |
| $SO_4$ | " | | | | |
| TDS | " | --- | 3760 | 1200 | 1050 |
| TOC | " | | | | |
| Zn | " | 0.04 | 0.35 | 0.20 | 0.05 |

Source: Cottonwood Gulch-
Federal Lease Tract C-6
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 0.035 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 9510 $cm^3$
Mean Leaching Rate: 0.0018 PV per hour
Mean Residence Time: 568 hours

TABLE A-8 COLONY NATURALLY LEACHED - RUN #1 (SATURATED)

| Parameter | Units | Volume of Effluent | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0.028 PV | 0.61 PV | 0.81 PV | 1.13 PV | 2.29 PV | 2.97 PV | 7.30 PV |
| Al | mg/l | <0.05 | 0.08 | 0.076 | 0.050 | <0.05 | <0.05 | <0.05 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 0.365 | 0.300 | 0.250 | 0.230 | 0.190 | 0.170 | 0.120 |
| Ba | " | 0.495 | 0.53 | 0.29 | 0.22 | 0.15 | 0.088 | 0.120 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 500 | 320 | 170 | 110 | 31 | 25 | 27 |
| Cl | " | 71 | 22 | 15 | 6.5 | 1.5 | 2.3 | 0.8 |
| $CO^3$ | " | 0.12 | 0.23 | 0.29 | 0.33 | 0.82 | 0.63 | 1.03 |
| Cr | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Cu | " | 0.31 | 0.23 | 0.18 | 0.15 | 0.08 | 0.05 | 0.039 |
| EC | µmhos/cm | 4200 | 2900 | 1600 | 1300 | 380 | 310 | 240 |
| F | mg/l | 5.2 | 5.7 | 6.7 | 6.2 | 7.5 | 8.7 | 6.9 |
| Fe | " | <0.03 | <0.03 | <0.03 | <0.03 | 0.08 | 0.08 | <0.03 |
| $HCO_3$ | " | 233 | 209 | 209 | 192 | 214 | 189 | 136 |
| Hg | " | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| K | " | 57 | 11 | 3.9 | 1.9 | 0.93 | 0.83 | 0.99 |
| Li | " | 0.012 | 0.01 | 0.006 | 0.004 | <0.004 | <0.004 | <0.004 |
| Mg | " | 365 | 200 | 120 | 73 | 20 | 17 | 19 |
| Mn | " | 0.07 | 0.11 | 0.11 | 0.11 | 0.082 | 0.068 | 0.070 |
| MO | " | 0.74 | 0.63 | 0.64 | 0.59 | 0.20 | 0.11 | 0.075 |
| Na | " | 350 | 210 | 160 | 120 | 48 | 33 | 14 |
| Ni | " | 0.06 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| $NO_3$ | " | 245 | 15 | 5.0 | 5.0 | 1.3 | 0.8 | <0.3 |
| Pb | " | 0.22 | 0.315 | 0.320 | 0.350 | 0.140 | 0.130 | 0.170 |
| pH | --- | 6.93 | 7.27 | 7.37 | 7.47 | 7.81 | 7.75 | 8.11 |
| Se | mg/l | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Si | " | 14.72 | 12.16 | 10.20 | 8.38 | 6.71 | 6.78 | 7.61 |
| Sn | " | 0.67 | 0.44 | 0.25 | 0.16 | 0.054 | 0.047 | 0.041 |
| $SO_4$ | " | | | | | | | |
| TDS | " | 4760 | 3160 | 2090 | 1180 | 300 | 220 | 120 |
| TOC | " | | | | | | | |
| Zn | " | 0.11 | 0.22 | 0.21 | 0.30 | 0.12 | 0.24 | 0.07 |

Source: Tailus Slope Material - Parachute Creek
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 2.5 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 7090 $cm^3$
Mean Leaching Rate: 0.0064 PV per hour
Mean Residence Time: 155 hours

TABLE A-9 UNION NATURALLY RETORTED - RUN #1 (SATURATED)

| Parameter | Units | Volume of Effluent | | | |
|---|---|---|---|---|---|
| | | 0.05 PV | 0.39 PV | 1.33 PV | 5.23 PV |
| Al | mg/l | <0.05 | <0.05 | <0.05 | <0.05 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 0.37 | 0.24 | 0.210 | 0.165 |
| Ba | " | 0.12 | 0.053 | 0.037 | 0.028 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 45 | 22 | 13 | 10 |
| Cl | " | 15 | 5.8 | 1.0 | 1.1 |
| $CO_3$ | " | 1.1 | <1.0 | 1.1 | 1.3 |
| Cr | " | 0.40 | 0.21 | 0.031 | <0.025 |
| Cu | " | 0.16 | 0.06 | <0.025 | <0.025 |
| EC | µmhos/cm | 1300 | 740 | 420 | 300 |
| F | mg/l | 5.4 | 7.4 | 5.6 | 8.3 |
| Fe | " | <0.05 | <0.05 | <0.05 | <0.05 |
| $HCO_3$ | " | 559 | 294 | 247 | 168 |
| Hg | " | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K | " | 55 | 15 | 11 | 9.2 |
| Li | " | 0.38 | 0.25 | 0.18 | 0.14 |
| Mg | " | 103 | 62 | 60 | 30 |
| Mn | " | 0.05 | <0.05 | <0.05 | <0.05 |
| MO | " | 0.32 | 0.25 | 0.125 | 0.065 |
| Na | " | 44 | 22 | 16 | 12 |
| Ni | " | <0.05 | <0.05 | <0.05 | <0.05 |
| $NO_3$ | " | 4.0 | 8.0 | 2.8 | 0.5 |
| Pb | " | 0.10 | 0.10 | 0.105 | 0.05 |
| pH | --- | 7.54 | 7.20 | 7.89 | 8.12 |
| Se | mg/l | <0.005 | <0.005 | <0.005 | <0.005 |
| Si | " | 11 | 10 | 12 | 8.8 |
| Sn | " | --- | --- | --- | --- |
| $SO_4$ | " | | | | |
| TDS | " | 1200 | 620 | 460 | 560 |
| TOC | " | | | | |
| Zn | " | 0.08 | 0.15 | 0.10 | 0.02 |

Source: Near Union Mine Portal - Parachute Creek
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 1.9 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 9330 $cm^3$
Mean Leaching Rate: 0.0075 PV p/hr
Mean Residence Time: 133 hours

TABLE A-10 COLONY SOIL - RUN #1 (SATURATED)

| Parameter | Units | Volume of Effluent | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0.10 PV | 0.47 PV | 0.83 PV | 1.11 PV | 1.50 PV | 2.49 PV | 4.30 PV |
| Al | mg/l | <0.05 | 0.15 | <0.05 | <0.05 | <0.05 | 0.07 | <0.05 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 0.70 | 0.69 | 0.70 | 0.64 | 0.68 | 0.53 | 0.47 |
| Ba | " | 0.40 | 0.20 | 0.20 | 0.19 | 0.22 | 0.12 | 0.22 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 960 | 650 | 400 | 350 | 450 | 200 | 40 |
| Cl | " | 200 | 10 | 6.5 | 2.8 | 0.1 | 1.4 | 0.15 |
| $CO_3$ | " | 0.17 | 0.48 | 0.59 | 0.61 | 0.46 | 1.04 | 1.50 |
| Cr | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Cu | " | 0.38 | 0.16 | 0.15 | 0.18 | 0.10 | 0.075 | 0.075 |
| EC | µmhos/cm | 9000 | 7500 | 6000 | 4800 | 5000 | 2000 | 370 |
| F | mg/l | 10 | 4.5 | 1.9 | 1.7 | --- | 1.4 | 1.8 |
| Fe | " | 0.01 | 0.03 | <0.01 | 0.06 | 0.52 | 0.18 | 0.01 |
| $HCO_3$ | " | 233 | --- | 205 | 206 | 175 | 192 | 152 |
| Hg | " | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| K | " | 270 | 200 | 150 | 130 | 150 | 50 | 25 |
| Li | " | 0.47 | 0.41 | 0.37 | 0.33 | 0.31 | 0.09 | 0.03 |
| Mg | " | 1450 | 1000 | 1150 | 1000 | 730 | 140 | 17 |
| Mn | " | 0.10 | 0.06 | 0.16 | 0.575 | 0.970 | 0.38 | 0.05 |
| MO | " | 0.84 | 0.68 | 0.55 | 0.65 | 0.45 | 0.17 | 0.07 |
| Na | " | 340 | 270 | 170 | 150 | 80 | 6.2 | 3.8 |
| Ni | " | 0.06 | 0.07 | 0.05 | 0.05 | 0.06 | 0.04 | 0.05 |
| $NO_3$ | " | 180 | 50 | 40 | 20 | 11 | <0.2 | <0.4 |
| Pb | " | 0.27 | 0.30 | 0.38 | 0.38 | 0.25 | 0.20 | 0.12 |
| pH | --- | 7.1 | 7.6 | 7.7 | 7.7 | 7.6 | 8.0 | 8.2 |
| Se | mg/l | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Si | " | 7.33 | 8.30 | 9.20 | 9.20 | 9.12 | 8.0 | 8.6 |
| Sn | " | <0.025 | 1.37 | 1.03 | 0.81 | 0.78 | 0.25 | 0.41 |
| $SO_4$ | " | | | | | | | |
| TDS | " | --- | --- | 7450 | 6850 | 6700 | 1850 | 250 |
| TOC | " | 512 | 272 | 138 | 96 | 68 | 44 | 19 |
| Zn | " | 0.65 | 0.40 | 0.55 | 0.30 | 0.12 | 0.02 | 0.01 |

Source: Near Mine Portal - Parachute Creek
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 1.8 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 7280 $cm^3$
Mean Leaching Rate: 0.0064 PV per hour
Mean Residence Time: 157 hours

TABLE A-11 USBM-RAW SHALE - UNSATURATED

| Parameter | Units | Volume of Effluent | |
|---|---|---|---|
| | | 0.31 PV | 14.5 PV |
| Al | mg/l | 4.15 | 7.54 |
| As | " | <0.005 | <0.005 |
| B | " | 10.08 | 0.42 |
| Ba | " | 0.065 | 0.045 |
| Be | " | <0.025 | <0.025 |
| Ca | " | 400 | 60 |
| Cl | " | 100 | 61 |
| $CO_3$ | " | 0.4 | 0.2 |
| Cr | " | <0.025 | <0.025 |
| Cu | " | 0.26 | 0.04 |
| EC | µmhos/cm | 6000 | 520 |
| F | mg/l | 24 | <0.5 |
| Fe | " | <0.1 | <0.1 |
| $HCO_3$ | " | 232 | 133 |
| Hg | " | <0.0001 | <0.0001 |
| K | " | 14 | 1.5 |
| Li | " | 1.7 | 0.05 |
| Mg | " | 420 | 13 |
| Mn | " | 2.5 | 0.19 |
| MO | " | 0.48 | 0.06 |
| Na | " | 690 | 40 |
| Ni | " | 0.38 | <0.05 |
| $NO_3$ | " | 17 | 10 |
| Pb | " | 0.29 | <0.05 |
| pH | --- | 7.45 | 7.35 |
| Se | mg/l | <0.005 | <0.005 |
| Si | " | 3.05 | <0.05 |
| Sn | " | --- | --- |
| $SO_4$ | " | | |
| TDS | " | --- | 384 |
| TOC | " | | |
| Zn | " | 2.5 | 0.11 |

Source: Saline Zone of the Green River Formation-USBM, Horse Draw Site
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 5 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 5400 $cm^3$
Mean Leaching Rate: 0.052 PV per hr.

TABLE A-12 C-a R-5 / MAHOGANY - UNSATURATED

| Parameter | Units | Volume of Effluent | | |
|---|---|---|---|---|
| | | 0.051 PV | 0.88 PV | 14.4 PV |
| Al | mg/l | 3.53 | 1.43 | 1.12 |
| As | " | <0.005 | <0.005 | <0.005 |
| B | " | 0.16 | <0.025 | <0.025 |
| Ba | " | 0.27 | 0.27 | 0.17 |
| Be | " | <0.025 | <0.025 | <0.025 |
| Ca | " | 1510 | 704 | 180 |
| Cl | " | 300 | 25 | 7.5 |
| $CO_3$ | " | <0.1 | 246 | 241 |
| Cr | " | 0.029 | 0.034 | 0.022 |
| Cu | " | 0.69 | 0.032 | <0.025 |
| EC | µmhos/cm | 37000 | 6500 | 1900 |
| F | mg/l | 208 ?? | <5.0 | 0.8 |
| Fe | " | <0.1 | <0.1 | <0.1 |
| $HCO_3$ | " | 403 | 11 | 9.1 |
| Hg | " | <0.0001 | <0.0001 | <0.0001 |
| K | " | 640 | 140 | 8.2 |
| Li | " | 0.09 | 0.06 | 0.02 |
| Mg | " | 108 | 9.7 | <0.675 |
| Mn | " | <0.05 | <0.05 | <0.05 |
| MO | " | 5.18 | 1.76 | 0.20 |
| Na | " | 7710 | 820 | 27 |
| Ni | " | 0.35 | 0.047 | <0.05 |
| $NO_3$ | " | 172 | 70 | 9.6 |
| Pb | " | 0.83 | 0.74 | <0.05 |
| pH | --- | 6.93 | 11.58 | 11.65 |
| Se | mg/l | <0.005 | <0.005 | <0.005 |
| Si | " | 23.28 | 7.05 | 2.7 |
| Sn | " | --- | --- | --- |
| $SO_4$ | " | | | |
| TDS | " | 30130 | 6365 | 610 |
| TOC | " | --- | --- | --- |
| Zn | " | 0.02 | 0.09 | <0.02 |

Source: R-a/Mahogany Zone-Lease Tract C-a
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 4.2 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 7463 $cm^3$
Mean Leaching Rate: 0.036 PV per hour

TABLE A-13 C-a COMPOSITE - UNSATURATED

| Parameter | Units | Volume of Effluent | | | |
|---|---|---|---|---|---|
| | | 0.13 PV | 1.13 PV | 1.84 PV | 19.54 PV |
| Al | mg/l | <0.05 | 0.69 | 0.31 | 0.058 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 1.97 | 1.1 | 0.56 | <0.025 |
| Ba | " | 0.22 | 0.157 | 0.16 | 0.075 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 970 | 536 | 230 | 21 |
| Cl | " | 130 | 3.9 | 1.1 | 0.83 |
| $CO_3$ | " | 0.7 | 0.5 | 0.4 | 0.3 |
| Cr | " | <0.025 | 0.043 | 0.020 | <0.025 |
| Cu | " | 0.44 | 0.057 | 0.031 | 0.052 |
| EC | µmhos/cm | 7500 | 5000 | 2900 | 125 |
| F | mg/l | <0.5 | 2.4 | 1.4 | 0.56 |
| Fe | " | <0.1 | <0.1 | <0.1 | <0.1 |
| $HCO_3$ | " | 1026 | 452 | 344 | 82 |
| Hg | " | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K | " | 63 | 16 | 6.0 | 0.6 |
| Li | " | 0.79 | 0.32 | 0.13 | <0.02 |
| Mg | " | 820 | 210 | 56 | 4.9 |
| Mn | " | 0.40 | 0.30 | 0.14 | <0.05 |
| MO | " | 1.68 | 1.25 | 0.54 | 0.48 |
| Na | " | 1240 | 211 | 56 | 4.3 |
| Ni | " | 0.16 | 0.11 | 0.055 | <0.05 |
| $NO_3$ | " | 52 | 11 | 3.4 | 8.7 |
| Pb | " | 0.77 | 0.70 | 0.47 | 0.055 |
| pH | --- | 7.03 | 7.30 | 7.32 | 7.73 |
| Se | mg/l | <0.005 | <0.005 | <0.005 | <0.005 |
| Si | " | 19.58 | 24.7 | 20.02 | 8.12 |
| Sn | " | --- | --- | --- | --- |
| $SO_4$ | " | | | | |
| TDS | " | 9450 | 3710 | 764 | 164 |
| TOC | " | | | | |
| Zn | " | 0.31 | 0.42 | 0.09 | <0.02 |

Source: Composite of Raised Bore Cuttings From G-Level in R-5 Zone to Surface - Lease Tract C-a
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 3.5 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 6344 $cm^3$
Mean Leaching Rate: 0.043 PV per hour

TABLE A-14 UNION NATURALLY RETORTED - UNSATURATED

| Parameter | Units | Volume of Effluent 0.09 PV |
|---|---|---|
| Al | mg/l | 0.10 |
| As | " | <0.005 |
| B | " | 0.39 |
| Ba | " | 0.35 |
| Be | " | <0.025 |
| Ca | " | 49 |
| Cl | " | 9.2 |
| $CO_3$ | " | 22 |
| Cr | " | 0.71 |
| Cu | " | 0.33 |
| EC | µmhos/cm | 1200 |
| F | mg/l | 6.6 |
| Fe | " | <0.0001 |
| $HCO_3$ | " | 585 |
| Hg | " | <0.0001 |
| K | " | 74 |
| Li | " | 0.51 |
| Mg | " | 108 |
| Mn | " | <0.05 |
| MO | " | 0.45 |
| Na | " | 75 |
| Ni | " | 0.05 |
| $NO_3$ | " | 3.4 |
| Pb | " | 0.16 |
| pH | --- | 8.81 |
| Se | mg/l | <0.005 |
| Si | " | 19.06 |
| Sn | " | --- |
| $SO_4$ | " | |
| TDS | " | 1085 |
| TOC | " | |
| Zn | " | 0.04 |

Source: Near Union Mine Portal-Parachute Creek
Leaching Solution: De-ionized Water
$D_{50}$ Particle Size: 1.9 mm

Bulk Volume: 18700 $cm^3$
Pore Volume: 9330 $cm^3$
Mean Leaching Rate: 0.051 PV per hour

TABLE A-15 LEACHATE QUALITY AFTER AERATION

| | | USBR Raw Shale After Drainage | | Colony Nat. Leached After Drainage | Colony Raw Shale After Drainage | | Colony Soil After Drainage |
|---|---|---|---|---|---|---|---|
| Parameter | Units | 0.33 PV | 6.02 PV | 0.06 PV | 0.093 PV | 7.89 PV | 0.15 PV |
| Al | mg/l | 2.75 | 0.40 | 0.17 | 0.75 | 0.11 | 0.37 |
| As | " | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| B | " | 3.9 | 0.34 | 0.16 | 0.87 | <0.025 | 0.76 |
| Ba | " | 0.061 | 0.075 | 0.19 | 0.11 | 0.07 | 0.57 |
| Be | " | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Ca | " | 458 | 47 | 42 | 400 | 40 | 190 |
| Cl | " | 22 | 4.1 | 1.4 | 11 | 1.1 | 2.2 |
| $CO_3$ | " | 0.3 | 0.9 | 0.5 | 0.2 | 0.4 | 2.9 |
| Cr | " | 0.033 | 0.038 | <0.025 | 0.04 | 0.014 | 0.022 |
| Cu | " | <0.025 | <0.025 | 0.064 | 0.11 | <0.025 | 0.190 |
| EC | µmhos/cm | 5400 | 400 | 460 | 2500 | 240 | 1700 |
| F | mg/l | 19 | 21 | 4.0 | 4.2 | 4.4 | 1.2 |
| Fe | " | 1.8 | 0.24 | <0.1 | <0.1 | <0.1 | <0.1 |
| $HCO_3$ | " | 175 | 138 | 206 | 123 | 111 | 480 |
| Hg | " | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K | " | 19 | 1.1 | 4.0 | 10 | 1.0 | 80 |
| Li | " | 0.22 | 0.02 | 0.02 | 0.07 | 0.02 | 0.18 |
| Mg | " | >460 | 16 | 28 | 140 | 5.5 | 110 |
| Mn | " | 0.33 | 0.14 | <0.05 | 0.95 | 0.074 | <0.05 |
| MO | " | 0.86 | 0.19 | 0.13 | 0.44 | 0.09 | <0.05 |
| Na | " | 310 | 31 | 16 | 50 | 5.8 | 18 |
| Ni | " | 0.51 | <0.05 | <0.05 | 0.059 | <0.05 | <0.05 |
| $NO_3$ | " | 14 | 15 | 48 | 28 | 3.5 | --- |
| Pb | " | <0.05 | 0.073 | 0.12 | 0.53 | 0.088 | 0.23 |
| pH | --- | 7.51 | 8.06 | 7.60 | 7.50 | 7.83 | 8.01 |
| Se | mg/l | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Si | " | 4.7 | 4.09 | 10.03 | 6.15 | 2.12 | 16.8 |
| Sn | " | --- | --- | --- | --- | --- | --- |
| $SO_4$ | " | | | | | | |
| TDS | " | 6130 | 230 | 350 | 2685 | 110 | 1470 |
| TOC | " | | | | | | |
| Zn | " | 3.0 | 0.02 | 0.02 | 0.44 | <0.02 | <0.02 |